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A STUDY TO DETERMINE FRICTION FACTORS OF MINE AIRWAYS

FINAL REPORT

By

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ABSTRACT

A program of field measurement work to determine airway friction factors was carried out in eleven Canadian mines representing nickel, copper, zinc, silver, gold, uranium, asbestos, potash and coal mining operations. The work was confined to straight, unobstructed lengths and included steel arched gangways, timbered sections and gunited surfaces as well as raw rock airways. Standard techniques were employed for airflow and pressure drop measurements and a photoprofiling method was used to characterize the airways. The results obtained in the igneous rock sites were generally lower than those in the well-known standard table of airway friction factors, reflecting the larger size and smoother conditions in the modern airways. A graph is constructed showing the theoretical relationship between friction factor and surface roughness for various nominal sizes of airway, with the experimental data from the present study super-imposed.

RÉSUMÉ

Un programme de travail pour déterminer les facteurs qui causent la friction dans les voies d'air des mines a été fait dans onze mines Canadiennes, qui répresentent les producters de nickel, de cuivre, de zinc, d'argent, d'or, d'uranium, d'amiante, de potasse et de charbon. Le travail était limité aux longueurs droites et non encombrées et était fait dans les passages arqués d'acier, les sections en bois, les surfaces en béton, et aussi les voies d'air dans la roche brute. Les techniques utilisées pour mesurer le mouvement d'air sont la perte de pression d'air et une methode de profil photograpique utilisée pour caractériser les voies d'air. Les résultats obtenus des locations de la roche pyrogène étaient généralement plus bas que ceux de la valeurs normale des facteurs de la friction dan les voies d'air de plus grandes demension et des voies d'air récentes. On a préparé un graphique qui explique le rapport theorique entre le facteur de la friction et l'inégalité d'air; les données expérimentales de l'étude courante ont été surimposées sur ce graphique.

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1.0 INTRODUCTION

This report describes a program of field measurement work designed to determine airway friction factors in a broad cross-section of Canadian mines. The objective of the study was to produce a table of friction factors (K factors) for different rock types and different types of airways within each rock type. A series of six field trips was planned to cover as wide a range of mining conditions as possible.

In the design of an underground mine ventilation system, the first step is to determine the volume of airflow required in all parts of the mine. A number of factors are involved in this determination such as quantities of dust and noxious gases to be diluted to safe levels, provision of adequate oxygen levels and maintenance of a comfortable temperature range. Various quantitative guidelines are available to aid in this selection.

Once the flow distribution has been determined, it is necessary to estimate the pressure required to force these air quantities through the respective mine openings for the selection and placement of fans and other ventilation controls. To do this the air is usually treated as an incompressible fluid and modified hydraulic formulae are used.

The principles underlying the accepted theory of mine ventilation were put forward by J.J. Atkinson in England in 1854. In its simplest form, Atkinson's equation states that the pressure drop in a mine airway is proportional to the square of the volume of air flowing, the constant of proportionality being defined as the resistance of the airway, or: -

$$P = R.Q^2 \qquad \text{--- (1)}$$

where P is the pressure drop, R is the resistance, and Q the

airflow rate.

The airway resistance, R, depends on the dimensions of the airway and the nature of the rubbing surface, such that: -

$$R = K.L.C / A^3 \qquad \text{--- (2)}$$

where K is regarded as a friction factor characterizing the roughness of the rock surface, L is the length of the airway, C is the perimeter of the airway cross section, and A is the cross-sectional area. The dimensional parameters are readily determined but some judgement is required in the selection of K.

Many mining companies measure representative K factors for their own internal use but, for planning purposes, the most widely used reference source dates back to a series of carefully conducted measurements carried out in the mid 1920's in the United States and first published by McElroy and Richardson[1]. This standard table of K factors has been reproduced in almost every comprehensive text on mine ventilation throughout the world since.

Measurements of K factors carried out in modern mine openings have generally indicated values lower than those in the U.S.B.M. table, particularly for the case of airways in igneous rock. This is understandable considering the mine openings in which the original work was done. Photographs of these airways[1] show that they were mostly between 2 and 2.5 m in diameter, with extremely rough rock surfaces. Modern mine openings, particularly in trackless mining zones, are generally much larger, and modern drilling and blasting techniques generally produce smoother walls. The relative roughness is thus reduced and since modern hydraulic theory shows that, for fully turbulent flow, the friction factor is purely a function of relative roughness of the conduit, we should expect lower values of the K

factor.

There is therefore a need to produce a table of airway friction factors more applicable to modern mining conditions. This need is augmented by the increasing trend to the use of computer network programs to solve mine ventilation problems. Accurate resistance values for each branch of the network are required for the basic data set for such programs.

Examination of equations (1) and (2) shows that the value of the K factor, as used in mine ventilation work, depends on the units chosen for length, pressure, and airflow rate. In the S.I. system, with lengths in m, pressures in Pa, and flow rates in m^3/s, the K factor has units of $N.s^2/m^4$, or kg/m^3 (i.e. units of density).

Comparison with the Darcy equation for pipe friction,

$$H_f = fLV^2 / 2gd$$

shows that, in S.I. units, K corresponds to $\rho f/8$ where f is the dimensionless hydraulic friction factor and d is the density of the ventilating air.

In other unit systems, K contains various unit conversion factors depending on the pressure and flow units used. Thus, K takes different values in different systems.

It has become customary, in mine ventilation work, to include standard air density in the K factor and apply corrections to calculated pressure drops according to the actual air density in the mine. When using S.I. units, however, a case can be made for separating the density term from the K factor, making the latter dimensionless.

For the purposes of this study, all measurements and

calculations were carried out in S.I. units. These units are very convenient for mine ventilation work and are becoming well established in the Canadian mining industry. The K factor values resulting from the study are expressed in S.I. units, dimensionless units, and English engineering units for comparative purposes.

In order to cover as wide a range of conditions as possible, initial contact was made with companies mining coal, potash, salt, gypsum, asbestos, uranium, nickel, copper, zinc, silver and gold. Under the terms of reference of the study, friction factors were determined in straight unobstructed airways only. No attempt was made to assess shock factors due to bends, contractions or other obstructions.

The data obtained are summarized in Table 1. For comparison purposes, data is tabled in Appendix 1 to illustrate differences between measured K factor parameters, obtained from this study, and the McElroy/Richardson standard tabled data.

TABLE 1

SUMMARY OF K FACTOR DATA

SITE NO.	MINE	ROCK TYPE OR SURFACE	NOMINAL DIMENSION	K FACTOR * A	B	C
1	Strathcona	Gunited	2.7 x 3.3	.00590	.00491	32
2	Strathcona	Timbered	2.6 x 2.6	.00953	.00794	51
3	Strathcona	Gunited	2.7 x 3.3	.00715	.00596	39
4	Strathcona	Gunited	2.7 x 3.3	.00717	.00598	39
5	Fraser	Footwall gneiss	5.0 x 4.0	.01163	.00969	63
6	Lockerby	Gunited	2.7 x 2.4	.00931	.00776	50
7	Lockerby	Gunited	2.7 x 2.4	.01083	.00903	58
8	Denison	(Quartz pebble	6.0 x 3.0	.00637	.00531	34
9	Denison	(conglomerate	5.0 x 3.0	.00921	.00767	50
10	King Beaver	Gunited	2.7 x 2.7	.01677	.01397	91
11	Camflo Malartic	(Sediments & (conglomerate	2.4 x 2.7	.01066	.00888	58
12	Kidd Creek	Andesite, basaltic	6.0 x 3.3	.00776	.00647	42
13	Kidd Creek	Andesite, basaltic	6.0 x 3.3	.00852	.00710	46
14	Kidd Creek	Dacite, mafic flow	4.0 x 3.0	.00860	.00717	46
15	Dome	Andesite, dacite	3.9 x 2.8	.01209	.01008	65
16	Dome	Flow breccia	3.9 x 2.8	.01110	.00925	60
17	Central	(	6.6 x 2.6	.00674	.00562	36
18	Canada	(Potash	7.1 x 3.2	.00473	.00394	26
19	Potash	(	7.1 x 3.2	.00548	.00457	30
20	Prince	Steel arches	5.2 x 3.5	.01050	.00875	56
21	Lingan	Steel arches	5.0 x 3.0	.01221	.01017	66

* A - at standard density (1.2 kg/m^3)

B - dimensionless (equivalent to (A/1.2))

C - English units ($\times 10^{-10}$) (equivalent to ($A \times 5.4 \times 10^3$) $\times 10^{-10}$)

2.0 TEST METHODS

In principle, the determination of mine airway K factors is quite simple. Using equation (1), the resistance of an airway can be calculated from a measurement of the pressure drop associated with a measured flow rate. From this resistance value and the relevant airway dimensions, the K factor can be calculated using equation (2).

In practice, of course, the process is much more difficult due to the irregularity of the airways, fluctuations in airflow rate and the practical difficulties associated with measuring flow rates and pressure drops to the required degree of accuracy.

2.1 Selection of Representative Airway

The first pre-requisite is the selection of a representative length of airway. Since the objective is to characterize the frictional nature of the airway surface, the airway chosen must be as uniform in nature as possible throughout its length. To avoid the masking influence of shock factors, it should be reasonably straight and unobstructed. Ideally, the longer the airway the more accurately the pressure drop can be measured. However, using the trailing tube method (described below) lengths are generally limited to about 150 m.

The accuracy of both pressure drop and flow rate measurements is improved at higher velocities of airflow. A minimum velocity of 3 m/s should be sought. In some cases it may be possible to arrange to have more airflow temporarily diverted to the survey section for the purposes of the measurements. Measuring pressure drops at two or more different flow rates gives a useful check on the results.

2.2 Preparation of Test Section

The length over which the pressure drop was to be determined was accurately measured with a tape, and the ends marked on the wall with a paint spray can. The perimeter and area were recorded at regular intervals along the section using a photoprofile technique described below. Representative photgraphs were also taken to illustrate the general nature and condition of the airway.

Two suitable locations for airflow measurement were selected, marked, and photoprofiled for each airway. Where possible, the flow measuring stations were selected outside the test section to cause minimum interference with the pressure drop measurement.

2.3 The Photoprofile Method

During previous work of this nature conducted by the Queen's Mining Department, a photographic method was devised to facilitate the measurement of areas and perimeters of irregularly shaped airways. In principle this involves the projection of a narrow band of light to illuminate the perimeter of an airway on a plane perpendicular to the airway axis. A polaroid camera is then used to photograph the illuminated band. A scale of known length is also illuminated in the plane of the profile to relate the dimensions of the photograph to the field dimensions.

Through experience, the following procedure has been developed for the photoprofiling technique:-

* Illumination is achieved by means of a miner's caplamp attached by a special adapter to a camera tripod such that the lamp can be rotated through a 360^{o} circle in a plane perpendicular to the airway axis.

* The lamp tripod is set up at the centre of the opening where the area is required and adjusted so that the light operates in the desired plane.

* The camera tripod is set up at an appropriate distance depending on the size of the opening and, the camera is mounted.

* If it is not possible to set the camera and light source at the centre of the opening (as, for example, where the back is very high) it is important that they are both at the same relative position in the cross-section.

* The camera is aimed so that the light source is in the centre of the field of view. This, together with the previous point, ensures that the focal plane of the camera is parallel to the illuminated plane, thus minimizing scale distortions.

* The light is shone into the corners of the area while the viewfinder is checked to ensure that the whole of the area is within the field of view. If part of the section is outside the field of view, it is important to move the camera back and not tilt it to suit.

* To take the picture, all lights in the area are extinguished and the camera shutter is opened.

* The caplamp is switched on and rotated once through a complete circle.

* The caplamp is switched off and a telescopic survey pole, set to as long a length as possible, is held in the plane of the profile so that it will be fully visible to the camera.

* The camera operator switches on his lamp and "paints" the pole once before closing the camera shutter.

* The picture is developed and checked to see that the profile and scale are fully visible and that the light source (which shows up as a small white circle) is at the centre of the picture.

* If satisfactory, the scale length and identifying details are marked on the back of the photograph which is then placed between the leaves of a notebook for protection. (It is better not to coat polaroid photographs underground as they then attract much dust.)

* Perimeters and areas are determined from the photographs by a simple computer program after tracing the outline and scale by means of a digitizer. A sample program listing for a handheld calculator is appended to this report to illustrate the photoprofile methodology.

Where the airway has a simple and regular shape, of course, the cross-sectional properties can be measured directly with a tape.

To illustrate the variability of the airways, composite plots were made of the digitized profiles for each test section. A small computer program was written to find the coordinate centre of each section, adjust all sections to the same scale and plot the super-imposed profiles at a convenient size together with an appropriate scale bar. These illustrations are included in the section describing the test locations. Examples of photoprofile pictures are shown in Figure 1.

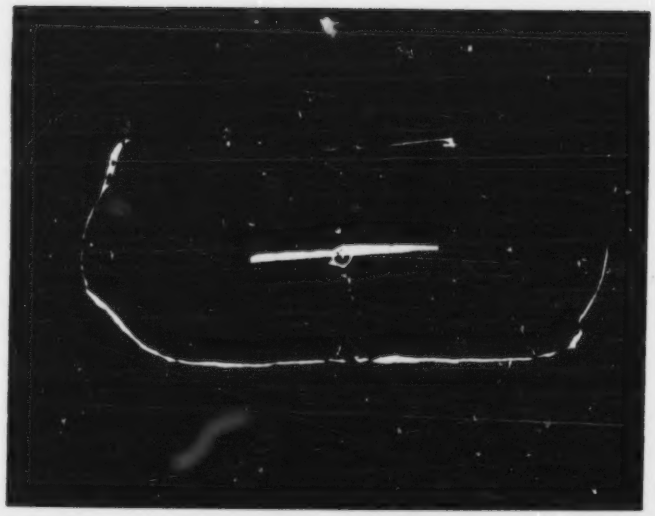


FIGURE 1: PHOTOPROFILE PICTURES

2.4 Airflow Measurement

Air flow rate is not measured directly but is determined as the product of velocity and cross-sectional area, each of which is measured separately. The area measurement has already been discussed above.

There are several methods of measuring air velocity and, since the velocity is not constant across the full cross-section, a technique must be used which gives a fair average. The standard rotating vane anemometer is commonly used for routine mine ventilation work, and although it is subject to large errors if carelessly used, by observing proper procedures, a good average velocity can be obtained.

In principle, the vane anemometer records the length of the column of air that passes through its axis during the time that it is switched on. Thus, if an anemometer is calibrated in metres, it is convenient to measure the airflow for a period of 100 seconds. Dividing the reading by 100 then gives the velocity in m/s. If it is calibrated in feet, it is more convenient to use one minute as the time period.

Since the velocity tends to be lower near the walls than in the centre of the airway, it is important to attempt to sample the airflow over the full cross-section as fairly as possible so that the measurement represents a weighted average velocity. This is sometimes achieved by traversing the anemometer slowly in a zigzag fashion over the area. The problem with this technique is that the operator has to move around to cover the full area and this affects the air currents. If extension rods are used to enable the operator to reach the far corners of the airway from one location, then they get in the way when trying to cover the closer parts.

The preferred technique is to hold the anemometer for

equal lengths of time at a number of positions, each of which represents an equal area of the airway, using extension rods where necessary, and keeping the body out of the airstream if possible.

The latter technique is more conveniently used with the second type of anemometer, namely the Electronic Direct Reading anemometer. This instrument also has a rotating vane, and is equipped with a power supply and associated circuitry which enables it to respond to the rate of rotation of the vanes so that it gives a continuous reading of velocity. Besides being more suitable for measuring velocity at selected points, this instrument is useful for observing the actual variations of velocity over the cross-section and monitoring the stability of the airflow over time.

Both of these types of anemometer were used at independent stations for each test airway.

2.5 Pressure Drop Measurement

There are basically two methods of measuring pressure drop over a length of mine airway, the barometric method and the gauge and tube method. The barometric method is favoured for complete mine resistance surveys where points may be widely separated. For K factor determination, the length of airway chosen must be straight and uniform. These restrictions mean that most of the test airways will be relatively short and the pressure drops small. Barometers measure the absolute pressure at each end of the airway and the pressure drop is obtained by subtraction. This difference is very small relative to the absolute pressure measured so the barometers have to be extremely sensitive, very carefully read, and periodically calibrated. Corrections for temperature, velocity, air density and elevation must be made for each reading. If the same barometer is used at both ends of the airway, allowance must be made for fluctuations in atmospheric pressure, and flow conditions must remain constant in the airway throughout the measurement period. If two barometers are used and read simultaneously at each end of the airway, the calibration of the two barometers over appropriate ranges of temperature and pressure becomes more significant. With all the adjustments and corrections required, the resolution achievable with barometric methods is not fine enough for short airways.

The gauge and tube method, which measures pressure drop directly, is inherently more accurate than the barometric method and was used exclusively for this study. In operation, a length of rubber tubing (about 150 m) is stretched out along the axis of the airway and connected at one end to one limb of a sensitive pressure difference measuring device. A short length of tubing is connected to the other limb of the pressure gauge.

An electronic micromanometer was used for the measurement of differential pressures, except in the coal mines, where a

magnehelic gauge was used.

The air flowing through the airway between the ends of the tubing suffers a loss of total pressure due to friction while the air in the tube is stationary. If the open ends of the tubing are pointed upstream at positions of mean velocity in the cross-section of the airway, the total pressure difference between the ends of the tube will be registered by the gauge. In practice, it is often difficult to select a point of mean velocity and it is more convenient to use a static tip at the ends of the tubes so that the gauge registers the difference in static pressure between the ends of the tube. For this survey, a pitot tube was mounted on a tripod and pointed upstream at the centre of the airway at each end of the test section. The static connections of the pitot tubes were connected to the manometer tubing. Since, for this work with reasonable lengths of airway, the air velocity was the same at both ends, the difference in static pressure was assumed to be the same as the difference in total pressure.

2.6 Air Density

In order to adjust the measured K factors to common terms, either in dimensionless form or at standard density, it is necessary to know the air density at which the pressure drop measurements are made.

K factor values calculated from equations (1) and (2) using measured P and Q values must be adjusted by a factor of 1.2/d for S.I. units, or by a factor of 1/d for dimensionless units, where d is the measured density.

Air density was determined from barometric pressure, and wet and dry bulb temperature readings, using standard psychrometric formulae. For this purpose, the barometric

pressure need not be as accurately determined as for pressure difference measurements. A Wallace and Tiernan altimeter was used for barometric pressure measurement.

2.7 Procedure

Introductory letters were mailed to mining companies in various geological environments seeking a tentative agreement to cooperate in the project. The following companies indicted a willingness to assist with the project:-

* Falconbridge Limited (Ni, Cu)
* Denison Mines Limted (U)
* Camflo Mines Limited (Au)
* Kidd Creek Mines Ltd. (Ag, Cu, Pb, Zn)
* Dome Mines Limited (Au, Ag)
* Asbestos Corp. (Asbestos)
* Central Canada Potash (Potash)
* Domtar Mines Limited (Gypsum)
* Canadian Salt Company (Salt)
* Cape Breton Development Corp. (Coal)

Final scheduling was arranged by telephone with the ventilation official or mine superintendent at each mine. The objectives of the study were pointed out and the mine official was asked to recommend suitable areas for the proposed work. Desirable conditions included a reasonably straight, uniform airway at least 150 m in length, and with a minimum air velocity of 3 m/s.

On arrival at the mine site, the study team visited the proposed test locations to generally assess their suitability. In many cases, it was found impossible to meet all the desired conditions at any one site. A shorter section could be tolerated if the velocity was high, and conversely, a low velocity could be offset by a longer length of airway. However, the maximum length

of tubing was 300 m.

Attempts to find a suitable location at the gypsum mine of Domtar Limited at Caledonia were unsuccessful. The air velocity was too low to give a measurable pressure drop over the lengths of airway available.

For the same reason, it was decided to eliminate the Ojibway Mine of the Canadian Salt Company, at Windsor, as the airways there were extremely large in cross-section with very low air velocity.

During the reconnaissance trips the direct reading anemometer was used to check the speed and unformity of the air current.

Selected test airways were measured, marked up and a series of photoprofile pictures taken at suitable intervals. A description of the airway was written and, in some cases, illustrative photographs were also taken of the general appearance of the airway.

The tubing was stretched out along the airway between the marked end points, taking care to avoid kinks, and the pitot-static tubes were mounted on tripods and pointed upstream at corresponding positions in the airway cross-section. The micromanometer was connected to the tubing and the barometer and psychrometer were set up nearby.

One team member read the pressure drop at five-minute intervals, while velocity measurements were made independently by the other two members. Generally, each observer made two complete sets of velocity measurements at each of the flow measuring stations, A and B.

Barometric pressure and wet and dry bulb temperatures were

read at the beginning and end of the work at each test section and a mean air density value was calculated from the two sets of readings using a pocket calculator programmed with the necessary psychrometric formulae.

The programmable calculator was also used to calculate the areas of the airflow measuring stations from the photoprofile pictures. This involved a somewhat laborious procedure so it was only used to permit calculation of flow rates in the field. This capability was considered to be important as it enabled the survey team to develop a "feel" for the validity of their measurements.

Additionally, the calculator was used to partially process all the data with respect to calculating anemometer calibration corrections and average velocities.

The bulk of the computation work was done at the university where the photoprofiles could be processed much more quickly and more accurately using a digitizer.

As mentioned above, dimensional comparison of the Atkinson and Darcy equations shows that K = f/8. The hydraulic formula for completely turbulent flow in rough conduits[2] gives:

$$f = 1/\{2 \log(14.8A/C)\}^2 \quad \text{--- (3)}$$

where = roughness height in consistent units.

Since airflow in mines is usually well into the turbulent range, this is a means of calculating K factors from airway dimensions and an assessment of surface roughness.

It was hoped that the photoprofile pictures, when digitized and superimposed, could be used as a measure of surface roughness. Although they give an idea of the variability of the

airways, they do not really provide a means of quantifying the roughness.

3.0 TEST LOCATION DESCRIPTIONS AND RESULTS

3.1 Test Location 1: Strathcona Mine

The first test location selected was on the 2500 level of the Strathcona Mine of Falconbridge Limited, located in the Sudbury Nickel belt area of Ontario. The test section, in the 2501 crosscut, was a tracked mainline fresh air intake drift, nominally 2.74 m x 3.35 m with a visually estimated roughness value of 0.30 m to 0.76 m. The walls and back were gunited, the travelling surface was dried mud and the shallow ditch was partially filled with water. A plan view and a typical cross section are shown in Figure 2, and the variability of the test section is illustrated in Figure 3, which is a superimposed plot of profiles of the airway taken at 6 m intervals.

The test section was located about 30 m downstream from a fresh air ventilation raise and extended for 58 m in length. An abrupt 45^{o} turn was situated 33.5 m downstream from the section, with some widening of the cross section 13.7 m upstream from the turn. The location was selected to avoid two small stations, shown in Figure 2, a diamond drill hole station and a drain station. Other obstructions in the airway were 2-inch, 5-inch, and 6-inch pipes and electrical cables suspended from the back.

3.2 Test Location 2: Strathcona Mine

The second test location, also in the 2501 crosscut, was in a slightly curved, timbered section, 76.2 m downstream of the 45^{o} turn referred to under Location 1. Figure 4 shows a plan view of the location and the arrangement of the timber sets.

The timber sets were constructed on 1.2 m centres with 25 cm square timbers, various sizes of round lagging, and some 5 cm x 24 cm planking. Hydraulic backfill, restrained by fabrene and wire mesh, was around the timber. The test section was 48.4 m

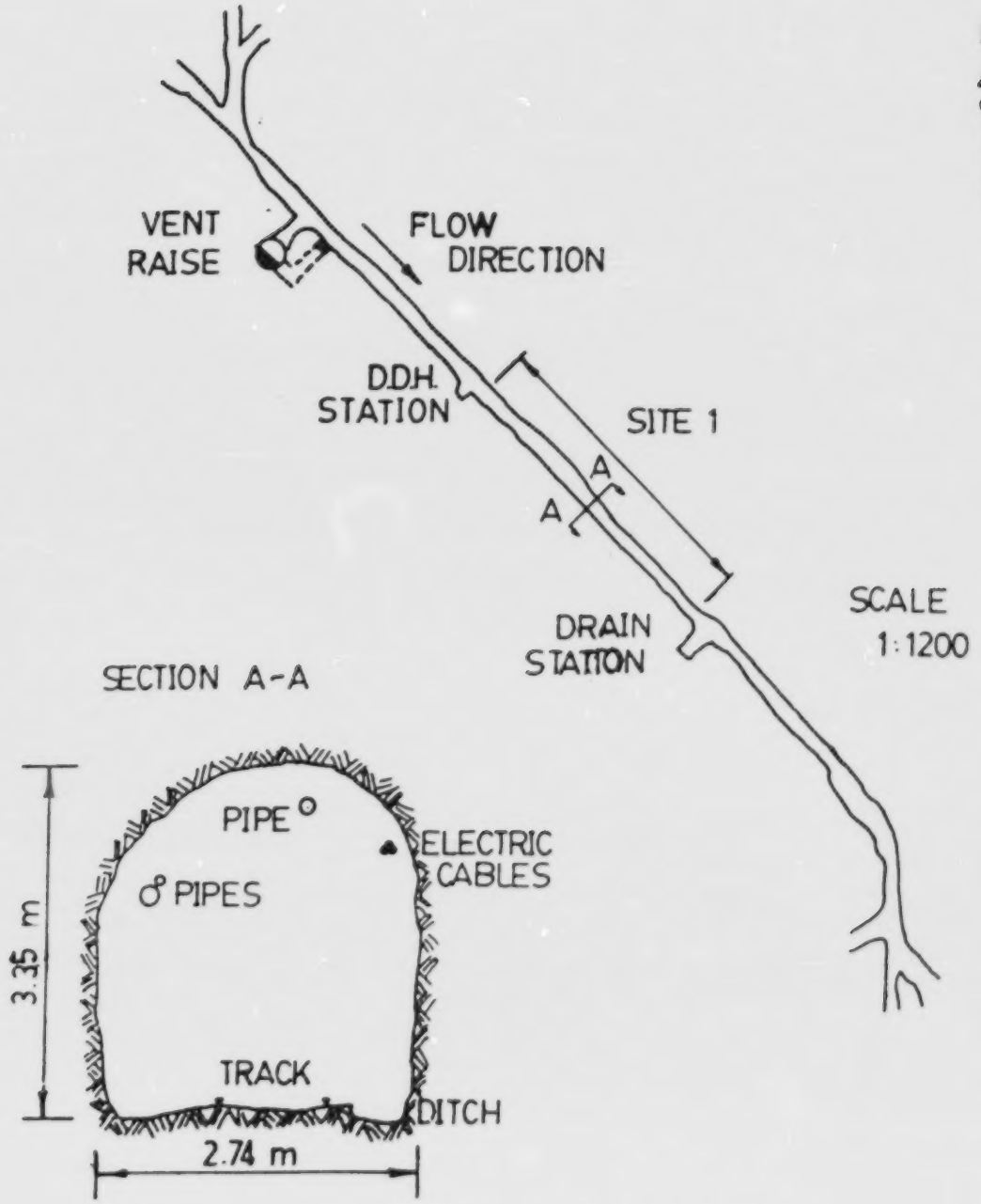


FIGURE 2: TEST SITE 1: STRATHCONA MINE, 2501 CROSS-CUT

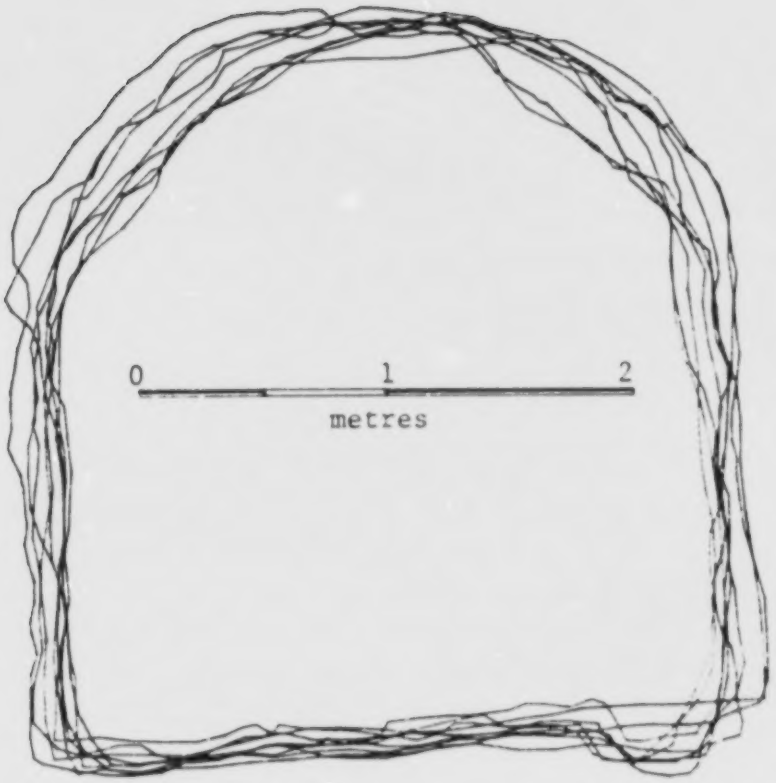


FIGURE 3: VARIABILITY OF TEST SITE 1

TABLE 2

DATA SUMMARY - TEST SITE 1

MINE: Strathcona LOCATION: 2501 cross-cut

ROCK/SURFACE TYPE: Gunited

LENGTH: 57.9 m NOMINAL SIZE: 2.7 X 3.3 (m)

PRESSURE DROP: 10.4 Pa AIR DENSITY: 1.301 kg/m^3

Section m	Perimeter m	Area m^2	Velocity m/s	Flow m^3/s
0 (A)	9.844	6.423	(A) 4.567	29.334
3	10.554	7.333	(A) 4.523	29.051
9	10.042	6.961	(A) 4.628	29.726
15	10.371	7.336	(A) 4.589	29.475
21	10.044	6.726	(A) 4.592	29.494
27	10.609	7.406	(A) 4.606	29.584
33	9.732	6.434	(B) 4.729	31.415
39	10.231	7.052	(B) 4.819	32.013
45	9.950	6.377	(B) 4.708	31.275
51	9.977	6.853	(B) 4.668	31.010
57 (B)	9.969	6.643		
Mean	10.148	6.912		30.238

K (Local density) = 0.00639 kg/m^3

K (Standard density) = 0.00590 kg/m^3

K (Dimensionless) = 0.00491

K (Old units) = 32

ε = 0.30 - 0.76 m (gunited surface)

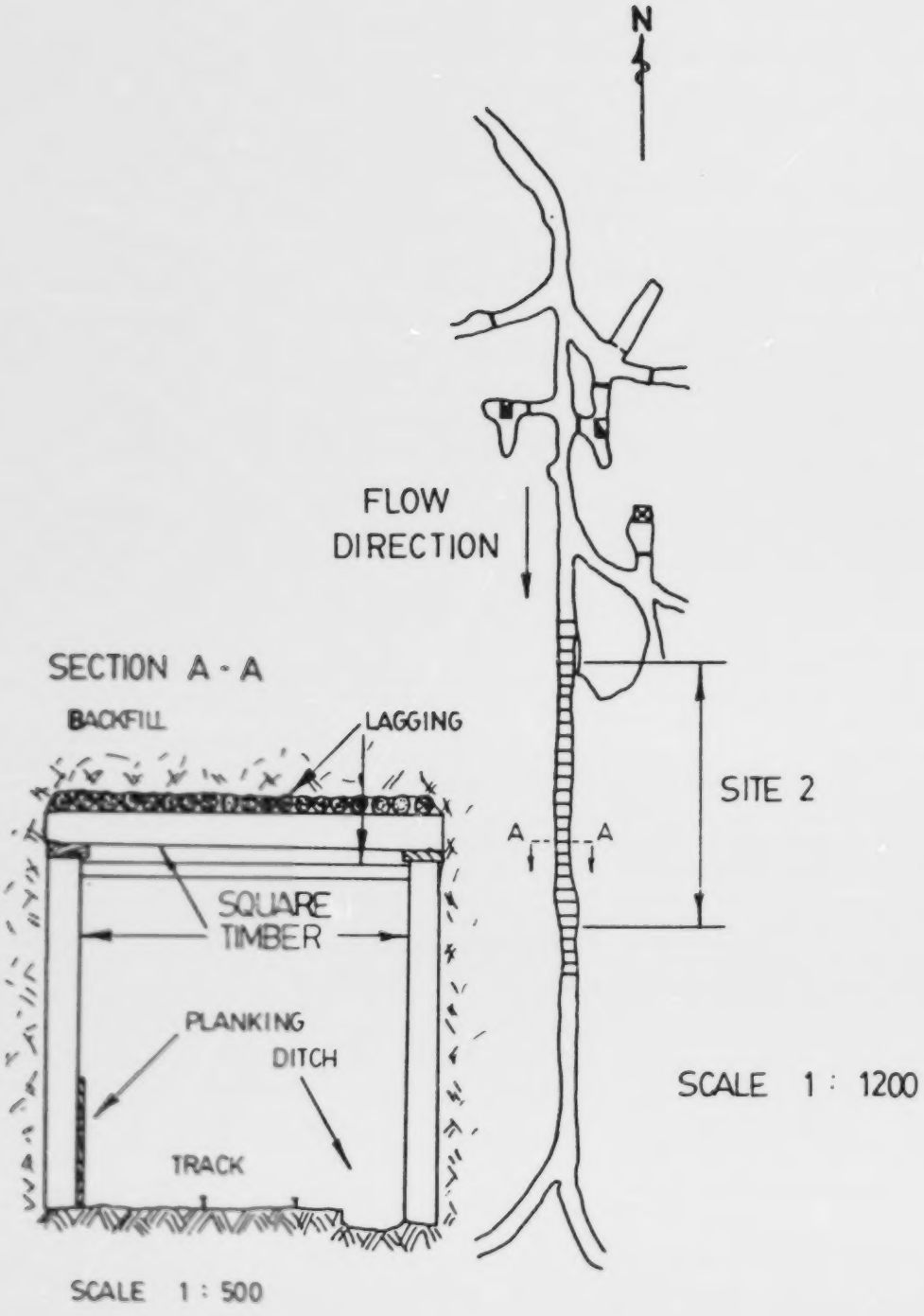


FIGURE 4: TEST SITE 2: STRATHCONA MINE. 2501 CROSS-CUT

TABLE 3

DATA SUMMARY - TEST SITE 2

MINE: Strathcona LOCATION: 2501 cross-cut

ROCK/SURFACE TYPE: Timbered

LENGTH: 48.4 m NOMINAL SIZE: 2.6 X 2.6 (m)

PRESSURE DROP: 4.63 Pa AIR DENSITY: 1.302 kg/m^3

Section m	Perimeter m	Area m^2	Velocity m/s	Flow m^3/s
(A)	10.340	6.682	(A) 2.450 (A) 2.464 (A) 2.370 (A) 2.461 (A) 2.551 (A) 2.365 (A) 2.381	16.371 16.464 15.836 16.444 17.046 15.803 15.910
Mean	10.340	6.682		16.268

K (Local density) = 0.01034 kg/m^3

K (Standard density) = 0.00953 kg/m^3

K (Dimensionless) = 0.00794

K (Old units) = 51

ε = 0.25 m (timber sets, 1.2 m centres)

in length. Measurements of the cross-section were made inside the timbers.

3.3 Test Location 3: Strathcona Mine

Test site 3 was located on the 2750 level of the Strathcona Mine in the 2701 crosscut, a tracked drift, nominally 2.74 m x 3.35 m. This is a mainline travelway from the shafts, handling return air, and with an estimated roughness of 0.30 m to 0.76 m. Heavy accumulations of dust were noted on the walls and back, and the floor consisted of hard packed mud with some softer areas near the partially filled drainage ditch. Lengths of 2-inch and 6-inch diameter pipe and electrical cable were hung on either side of the drift. A plan view and typical cross-section are shown in Figure 5, and the variability of the section is illustrated in Figure 6.

The site was 61 m in length and was located 30.5 m downstream from an exploration drive junction, avoiding two small safety bays, and 42.7 m upstream from another junction.

3.4 Test Location 4: Strathcona Mine

Test location 4 was the same as number 3 but extended an additional 23 m downstream, and included a shallow safety bay, as indicated in Figure 5.

3.5 Test Location 5: Fraser Mine

Test site 5 was located on the 34 level of the Fraser Mine of Falconbridge Limited. The site was a designated fresh air intake ramp dipping in the downstream direction at about 10%, with a screened and bolted back and coarse rock roadway. The rock type was known locally as fine grained footwall gneiss and had an estimated roughness of 0.5 m to 0.6 m. Shallow

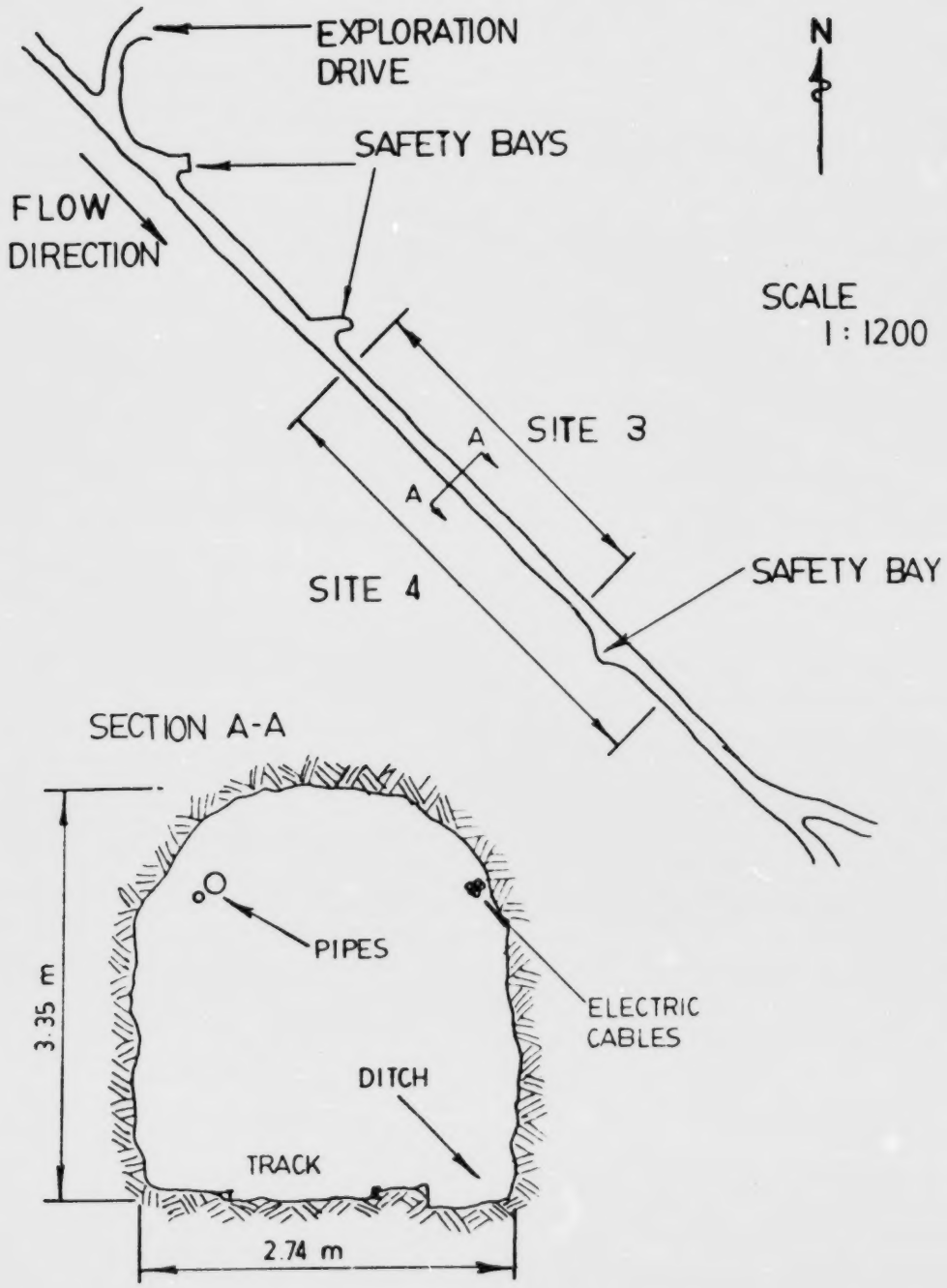


FIGURE 5: TEST SITES 3 & 4: STRATHCONA MINE, 2701 CROSS-CUT

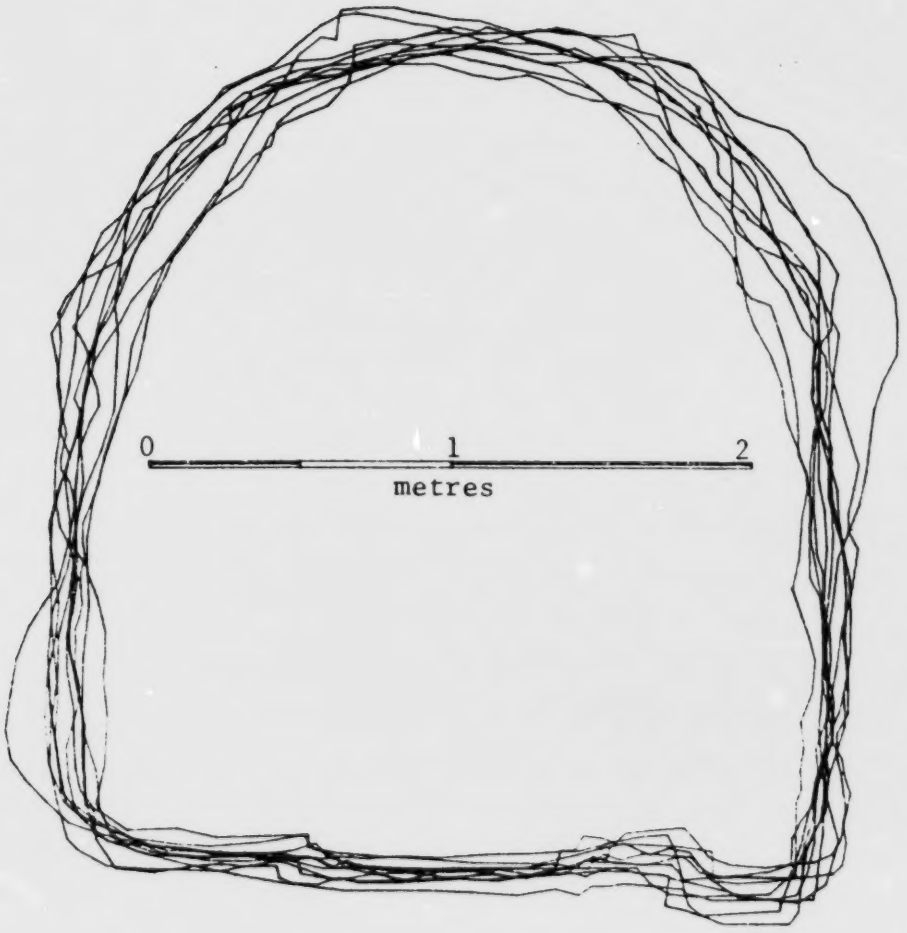


FIGURE 6: VARIABILITY OF TEST SITES 3 AND 4

TABLE 4

DATA SUMMARY - TEST SITE 3

MINE: Strathcona LOCATION: 2701 cross-cut

ROCK/SURFACE TYPE: Gunited

LENGTH: 57.9 m NOMINAL SIZE: 2.7 X 3.3 (m)

PRESSURE DROP: 26.07 Pa AIR DENSITY: 1.289 kg/m^3

Section m	Perimeter m	Area m^2	Velocity m/s	Flow m^3/s
0 (A)	9.283	6.043	(A) 6.096	36.838
7.6	9.282	5.747	(A) 6.116	36.959
15.2	9.934	6.586	(A) 6.065	36.651
22.8	9.526	6.104	(A) 6.150	37.164
30.5	9.536	6.237	(B) 5.656	33.229
38.1	8.891	5.262	(B) 5.641	33.141
45.7	9.480	6.050		
53.3	9.178	5.728		
61.0	9.526	6.164		
(B)*		5.875		
Mean	9.404	5.989		35.664

* Section not included in test length

K (Local density) = 0.00768 kg/m^3

K (Standard density) = 0.00715 kg/m^3

K (Dimensionless) = 0.00596

K (Old units) = 39

ε = 0.30 - 0.76 m (gunited surface)

TABLE 5

DATA SUMMARY - TEST SITE 4

MINE: Strathcona LOCATION: 2701 cross-cut

ROCK/SURFACE TYPE: Gunited

LENGTH: 83.8 m NOMINAL SIZE: 2.7 X 3.3 (m)

PRESSURE DROP: 33.33 Pa AIR DENSITY: 1.289 kg/m^3

Section m	Perimeter m	Area m^2	Velocity m/s	Flow m^3/s
0 (A)	9.283	6.043	(A) 5.604	33.865
7.6	9.282	5.747	(B) 5.029	30.290
15.2	9.934	6.586	(B) 5.644	33.994
22.8	9.526	6.104	(B) 6.003	36.156
30.5	9.536	6.237	(B) 6.130	36.921
38.1	8.891	5.262		
45.7	9.480	6.050		
53.3	9.178	5.728		
61.0	9.526	6.164		
76.2	9.241	5.875		
83.8	9.438	5.945		
(B) *		6.023		
Mean	9.393	5.973		34.245

* Section not included in test length

K (Local density) = 0.00769 kg/m^3

K (Standard density) = 0.00716 kg/m^3

K (Dimensionless) = 0.00597

K (Old units) = 39

ε = 0.30 - 0.76 m (gunited surface)

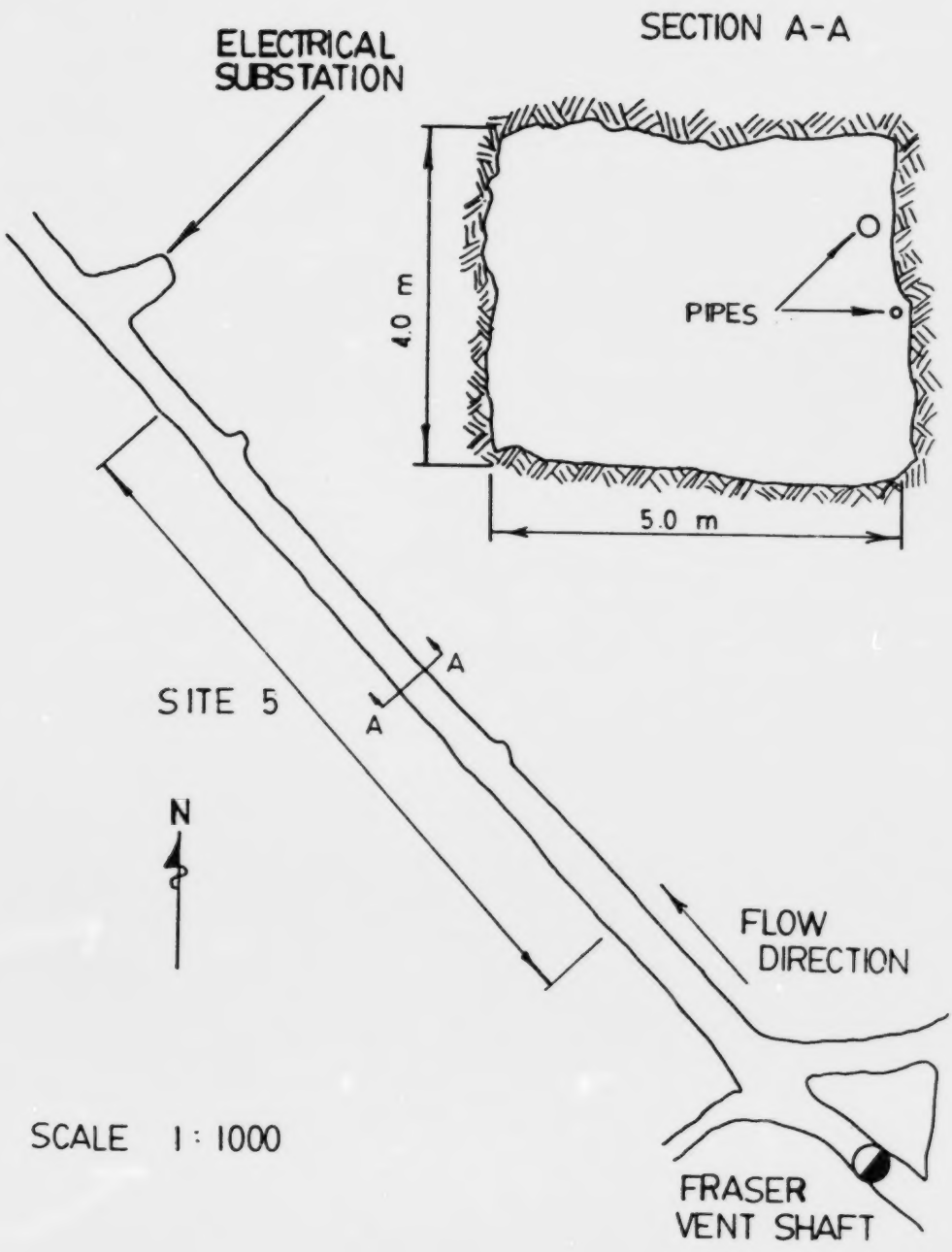


FIGURE 7: TEST SITE 5: FRASER MINE, 34-575 VENT. RAMP

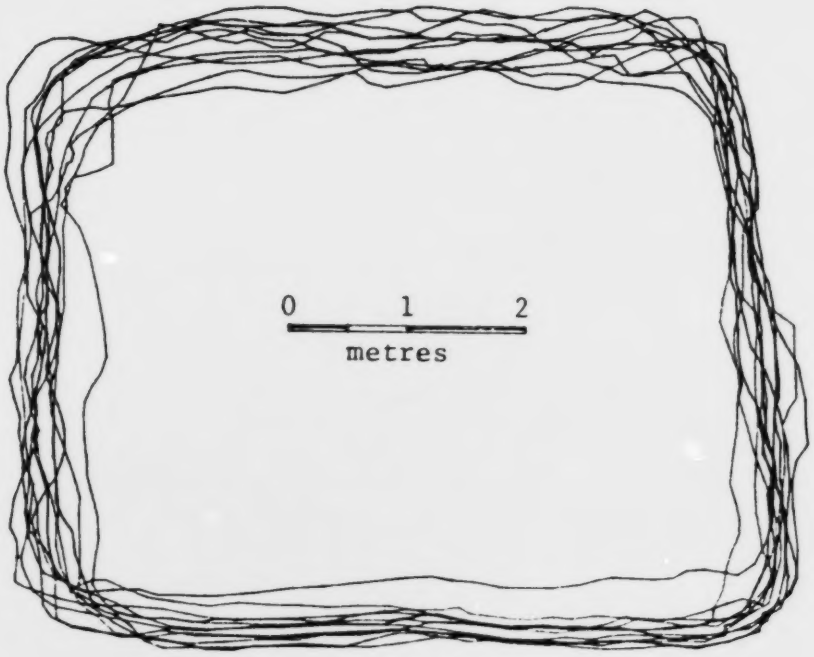


FIGURE 8: VARIABILITY OF TEST SITE 5

TABLE 6

DATA SUMMARY - TEST SITE 5

MINE: Fraser LOCATION: 34-575 Vent. Ramp

ROCK/SURFACE TYPE: Footwall gneiss

LENGTH: 104.5 m NOMINAL SIZE: 5.0 X 4.0 (m)

PRESSURE DROP: 25.5 Pa AIR DENSITY: 1.324 kg/m^3

Section m	Perimeter m	Area m^2	Velocity m/s	Flow m^3/s
(A) *		27.924	(A) 5.312	148.332
0	20.609	28.353	(A) 5.236	146.210
7.6	20.937	27.546	(A) 5.264	146.992
15.2	21.938	30.374	(B) 6.071	136.504
22.8	20.294	26.590	(B) 6.137	137.997
30.5	21.120	28.700		
38.1	20.967	30.226		
45.7	21.163	20.855		
53.3	20.388	26.833		
61.0	21.340	29.172		
68.6	20.383	28.557		
76.2	21.168	30.513		
83.8	20.043	25.495		
91.5	19.365	24.695		
104.5	20.112	26.333		
(B) *		22.486		
Mean	20.702	28.160		143.207

* Section not included in test length

K (Local density) = 0.01283 kg/m^3

K (Standard density) = 0.01163 kg/m^3

K (Dimensionless) = 0.00969

K (Old units) = 63

ε = 0.5 - 0.6 m (uncoated, rock surface)

undulations were noted in the roadway and also in the back. The 5 m x 4 m airway, shown in Figure 7, included two 0.9 m deep safety bays at 30 m intervals along its 105 m length. Two lengths of 6-inch and 2-inch pipe were other obstructions. The upstream station was located 26 m downstream from the fresh airway junction and the downstream station was located 48 m upstream from the main haulage drift junction and just upstream from an electrical substation. Variability of the section is shown in Figure 8.

3.6 Test Location 6: Lockerby Mine

The 42-110 drift, on the 4200 level of the Lockerby Mine, was chosen for test site No. 6. The tracked and gunited drift, nominally 2.4 m x 2.7 m, had a fine gravel and mud floor and a partially water-filled ditch. The roughness was estimated to be 0.5 m to 0.6 m. Lengths of 2-inch pipe, 6-inch pipe and electrical cable were hung at the shoulders of the drift. Figures 9 and 10 show the plan view, a typical cross section, and the variability. The site was 76.2 m in length with 27 m of uniform length upstream and 16 m of uniform length downstream to a safety bay.

3.7 Test Location 7: Lockerby Mine

Test site 7 was located on the 3825 level of Falconbridge's Lockerby Mine, along the 38-160 drift. The site was nominally 2.4 m x 2.7 m in cross-section, and 112.8 m in length with 27.4 m of uniform length upstream to a ventilation control door. Just beyond the door was a 25° turn and 36.6 m further upstream was the No. 2 shaft intake for the level. A refuge station was located 18.3 m downstream from the section, and a shallow powder magazine was located about half-way along the section. The drift was gunited and could be described as very blocky, with an estimated roughness of 0.3 m to 0.6 m. The travelling surface was dry with fine gravel and mud between, and

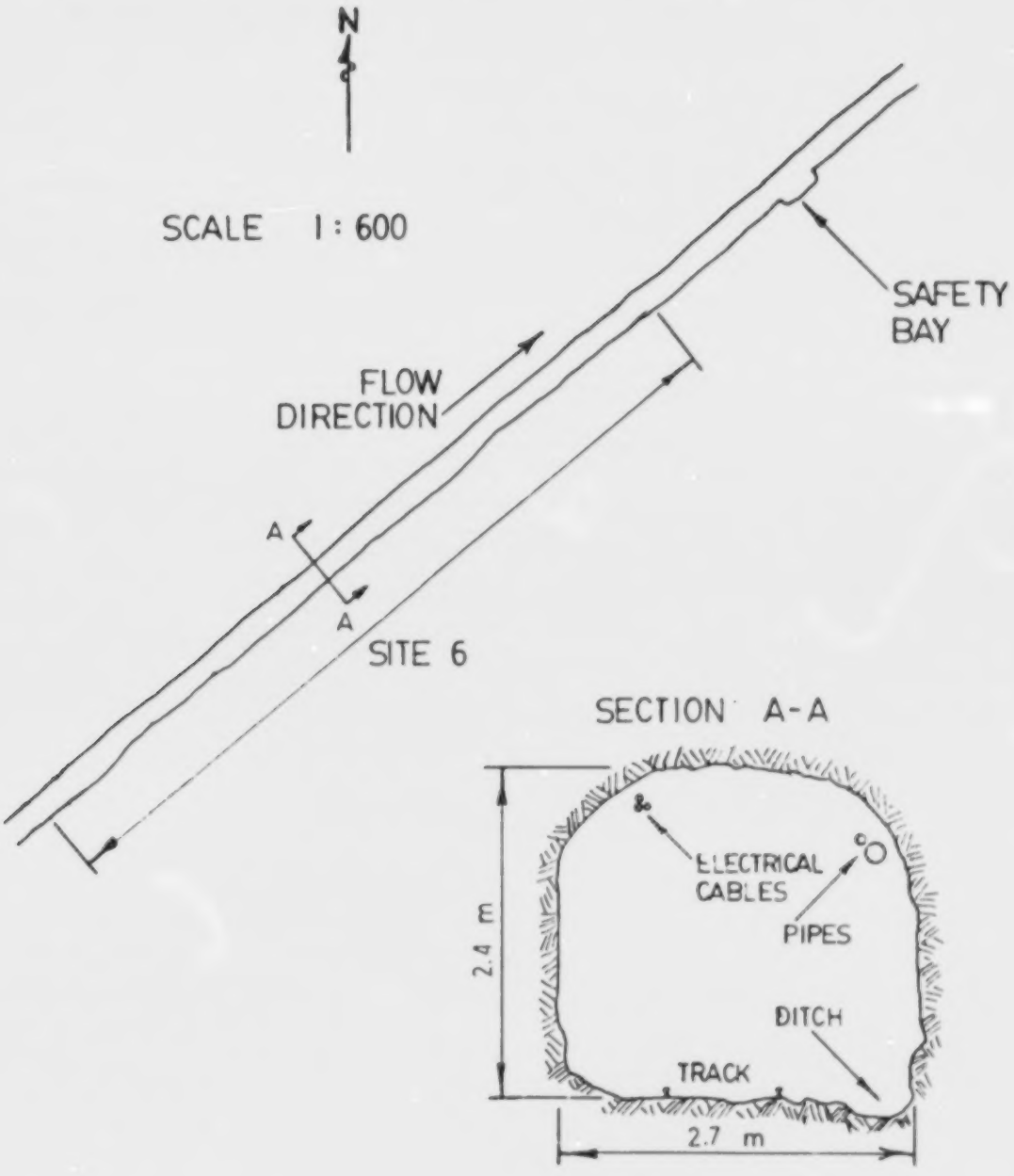


FIGURE 9: TEST SITE 6: LOCKERBY MINE, 42-110 DRIFT

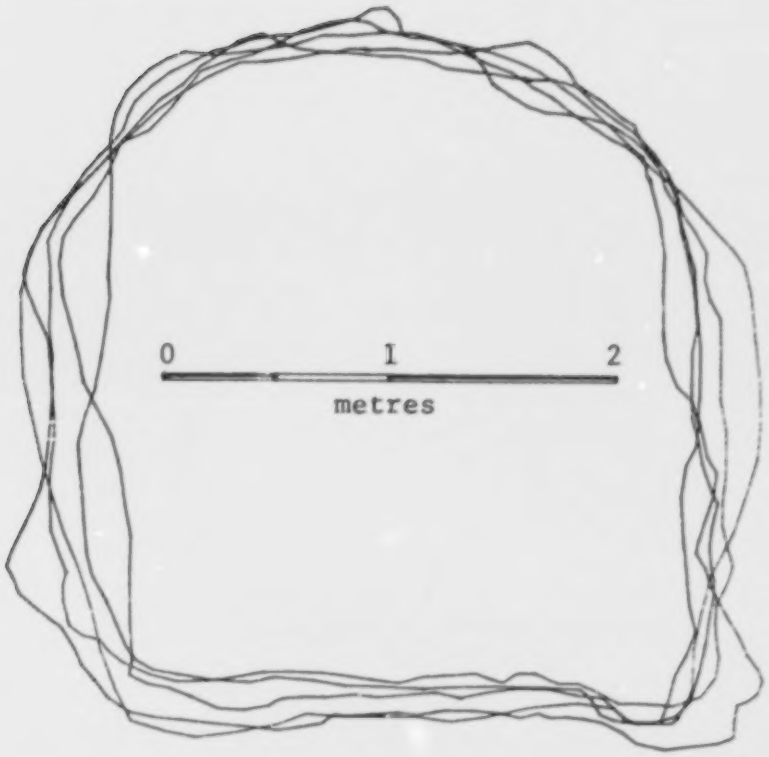


FIGURE 10: VARIABILITY OF TEST SITE 6

TABLE 7

DATA SUMMARY - TEST SITE 6

MINE: Lockerby LOCATION: 42-110 Drift

ROCK/SURFACE TYPE: Gunited

LENGTH: 76.2 m NOMINAL SIZE: 2.7 x 2.4 (m)

PRESSURE DROP: 2.5 Pa AIR DENSITY: 1.335 kg/m^3

Section m	Perimeter m	Area m^2	Velocity m/s	Flow m^3/s
(A) *		7.058	(A) 1.564	11.735
0	11.067	7.909	(B) 1.507	10.875
15.2	10.194	7.279	(B) 1.586	11.445
30.5	10.160	6.970	(B) 1.541	11.120
45.7	10.529	8.015		
61.0	9.946	6.692		
76.2	10.654	7.600		
(B) *		7.216		
Mean	10.425	7.411		11.119

* Section not included in test length

K (Local density) = 0.01036 kg/m^3

K (Standard density) = 0.00931 kg/m^3

K (Dimensionless) = 0.00776

K (Old units) = 50

ε = 0.5 - 0.6 m (gunited surface)

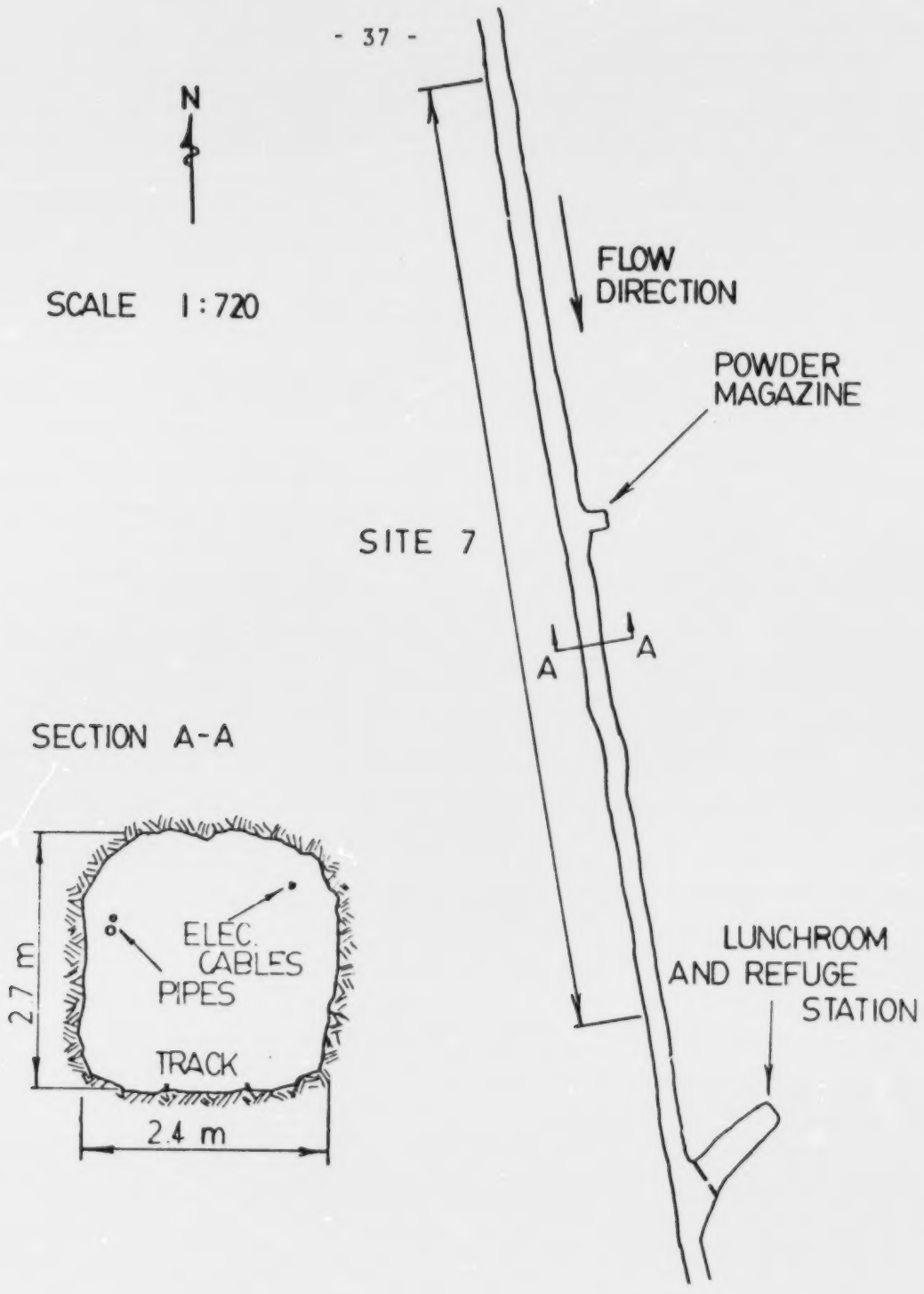


FIGURE 11: TEST SITE 7: LOCKERBY MINE, 38-160 DRIFT

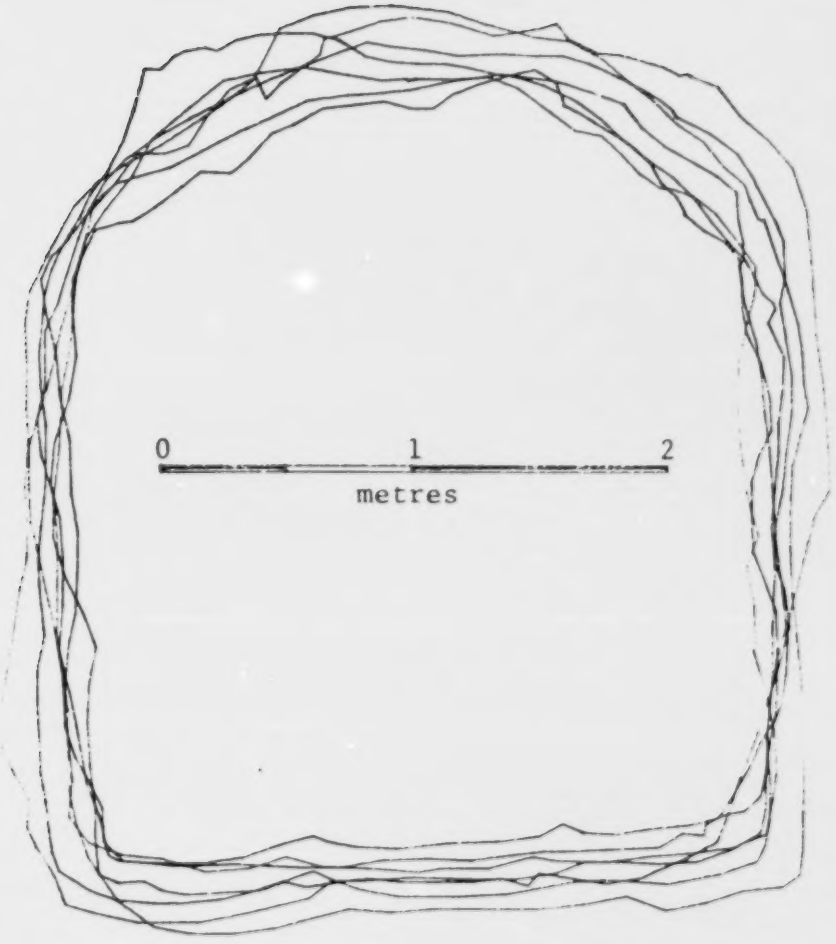


FIGURE 12: VARIABILITY OF TEST SITE 7

TABLE 8

DATA SUMMARY - TEST SITE 7

MINE: Lockerby LOCATION: 38-160 Drift

ROCK/SURFACE TYPE: Gunited

LENGTH: 112.8 m NOMINAL SIZE: 2.7 x 2.4 (m)

PRESSURE DROP: 23.6 Pa AIR DENSITY: 1.333 kg/m^3

Section m	Perimeter m	Area m^2	Velocity m/s	Flow m^3/s
(A) *		7.481	(A) 4.081	30.530
0	10.838	8.328	(A) 4.067	30.425
15.2	11.404	9.317	(A) 4.095	30.635
30.5	10.262	7.427	(B) 3.569	28.688
61.0	11.583	9.276	(B) 3.647	29.315
77.1	10.892	8.504	(B) 3.569	28.688
91.5	10.460	7.598	(B) 3.714	29.853
106.7	10.202	7.297		
112.8	10.643	7.729		
(B) *		8.038		
Mean	10.785	8.185		29.733

* Section not included in test length

K (Local density) = 0.01203 kg/m^3

K (Standard density) = 0.01083 kg/m^3

K (Dimensionless) = 0.00903

K (Old units) = 58

ε = 0.3 - 0.6 m (gunited surface)

to the sides of the track. Obstructions included lengths of 2-inch and 6-inch pipe on one shoulder of the drift and electrical cables on the opposite shoulder. Details of the site are shown in Figures 11 and 12.

3.8 Test Location 8: Denison Mine

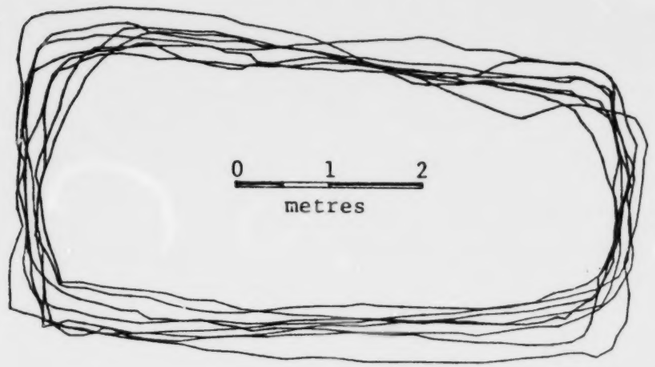
Denison Mine, at Elliot Lake, was the location of sites 8 and 9. Site 8 was within the 95588 fresh airway in the "B" reef. The designated fresh airway, driven in quartz pebble conglomerate, was dry and dusty, with a nominal size of 3 m x 6 m. It had a coarse rock, slightly undulating roadway, dipping about 18 degrees to the south or downstream. The walls were relatively smooth while the bolted back had an estimated roughness of 0.15 m to 0.20 m. There were uniform lengths of 12.8 m and 19.8 m, upstream and downstream from the 106.7 m section, respectively. The variability of the cross section can be seen in Figure 13.

3.9 Test Location 9: Denison Mine

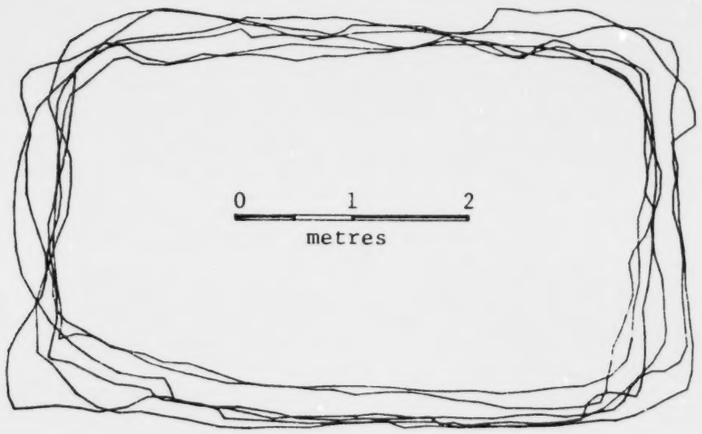
Test site 9 was in the 40950 exhaust airway, located in one fork of the Canmet drive at Denison Mine. The roadway dipped slightly downstream and was wet and muddy with coarse rock strewn to both sides of the drift. The quartz pebble conglomerate, which made up the walls and bolted back, was heavily coated with diesel soot and had an estimated roughness of 0.15 m to 0.20 m. The section was 91.4 m in length with 21.3 m of uniform length upstream and 6.1 m of uniform length downstream. The nominal cross-section of 3 m x 5 m was obstructed by two lengths of pipe and electrical cables. Variability of the section is illustrated in Figure 13.

3.10 Test Location 10: King Beaver Mine

Site 10 was located on the 1000 haulage level of the King



Test Site 8



Test Site 9

FIGURE 13: TEST SITES 8 & 9: DENISON MINE

TABLE 9

DATA SUMMARY - TEST SITE 8

MINE: Denison LOCATION: 95588 Intake airway

ROCK/SURFACE TYPE: Quartz pebble conglomerate

LENGTH: 106.7 m NOMINAL SIZE: 6.0 X 3.0 (m)

PRESSURE DROP: 73.1 Pa AIR DENSITY: 1.267 kg/m^3

Section m	Perimeter m	Area m^2	Velocity m/s	Flow m^3/s
0 (A)	17.221	16.690	(A) 10.55	176.080
15.2	18.889	20.300	(A) 10.50	175.245
30.5	16.104	14.867	(A) 10.12	168.903
45.7	17.241	17.821	(A) 10.08	168.235
61.0	15.763	14.467	(B) 8.89	174.360
76.2	17.028	17.735	(B) 8.83	173.183
91.5	17.646	18.187	(B) 8.77	172.006
106.7	17.470	17.264	(B) 9.07	177.890
(B) *		19.613		
Mean	17.170	17.166		173.237

* Section not included in test length

K (Local density) = 0.00673 kg/m^3

K (Standard density) = 0.00637 kg/m^3

K (Dimensionless) = 0.00531

K (Old units) = 34

ε = 0.15 - 0.2 m (uncoated, rock surface)

TABLE 10

DATA SUMMARY - TEST SITE 9

MINE: Denison LOCATION: 40950 Exhaust airway

ROCK/SURFACE TYPE: Quartz pebble conglomerate

LENGTH: 91.4 m NOMINAL SIZE: 5.0 X 3.0 (m)

PRESSURE DROP: 61.4 Pa AIR DENSITY: 1.252 kg/m^3

Section m	Perimeter m	Area m^2	Velocity m/s	Flow m^3/s
(A) *		14.266	(A) 8.79	125.398
0	15.434	15.465	(A) 8.39	119.692
15.2	15.888	16.127	(A) 9.07	129.393
33.5	16.115	16.733	(A) 8.52	121.546
45.7	14.854	13.957	(B) 8.04	132.628
61.0	17.463	17.191	(B) 8.09	133.453
76.2	14.378	13.254	(B) 8.18	134.937
91.5	15.561	15.357		
(B) *		16.496		
Mean	15.670	15.440		128.150

* Section not included in test length

K (Local density) = 0.00960 kg/m^3

K (Standard density) = 0.00921 kg/m^3

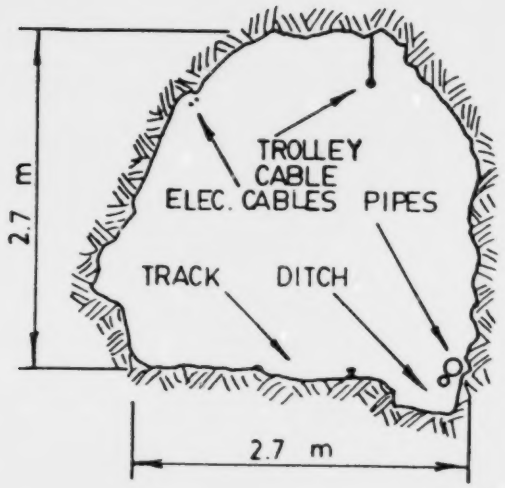
K (Dimensionless) = 0.00767

K (Old units) = 50

ε = 0.15 - 0.2 m (uncoated, rock surface)

Beaver Mine of the Asbestos Corporation at Thetford Mines, Quebec. The gunited drift, with an average cross sectional area of 7.3 m^2, was highly fractured, with an estimated roughness of 0.3 m to 0.5 m. The back was screened and bolted while the tracked travelling surface was wet and muddy. There were 6 small safety bays along the 152.4 m length, with 4-inch and 2-inch pipes laid alongside the ditch. Electrical cables and a trolley cable were suspended from the back. There was a uniform length of 40 m upstream to a junction and 11 m of uniform length downstream to another junction. A typical cross section and the variability can be seen in Figure 14.

SITE 10 CROSS SECTION



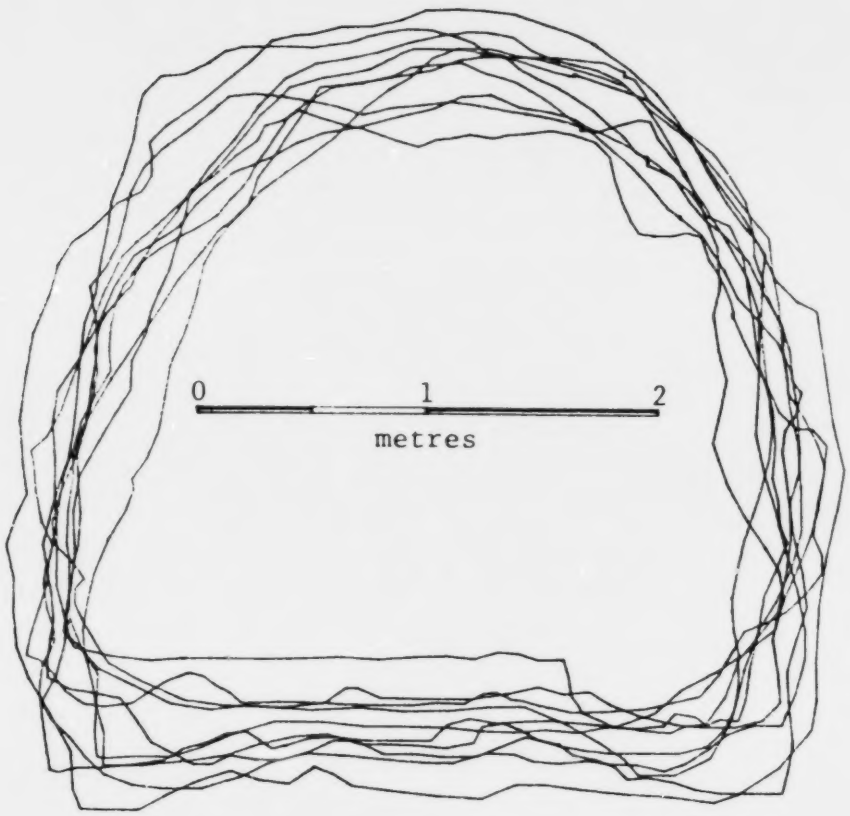


FIGURE 14: LAYOUT AND VARIABILITY OF TEST SITE 10: KING BEAVER MINE

TABLE 11

DATA SUMMARY - TEST SITE 10

MINE: King Beaver Asbestos LOCATION: 1000 Haulage Level

ROCK/SURFACE TYPE: Gunited

LENGTH: 152.4 m NOMINAL SIZE: 2.7 x 2.7 (m)

PRESSURE DROP: 8.53 Pa AIR DENSITY: 1.203 kg/m^3

Section m	Perimeter m	Area m^2	Velocity m/s	Flow m^3/s
(A) *		7.110	(A) 1.496	10.637
0	10.814	7.939	(A) 1.479	10.516
15.2	10.355	7.288	(A) 1.462	10.395
30.5	11.943	9.887	(B) 2.083	12.623
45.7	10.920	8.099	(B) 2.057	12.465
61.3	11.394	8.675	(B) 2.049	12.417
76.2	10.400	7.145		
91.5	10.020	6.896		
106.7	9.911	6.803		
122.3	10.213	6.469		
137.2	10.225	6.587		
152.4	10.269	6.670		
(B) *		6.060		
Mean	10.588	7.496		11.509

* Section not included in test length

K (Local density) = 0.01681 kg/m^3

K (Standard density) = 0.01677 kg/m^3

K (Dimensionless) = 0.01397

K (Old units) = 91

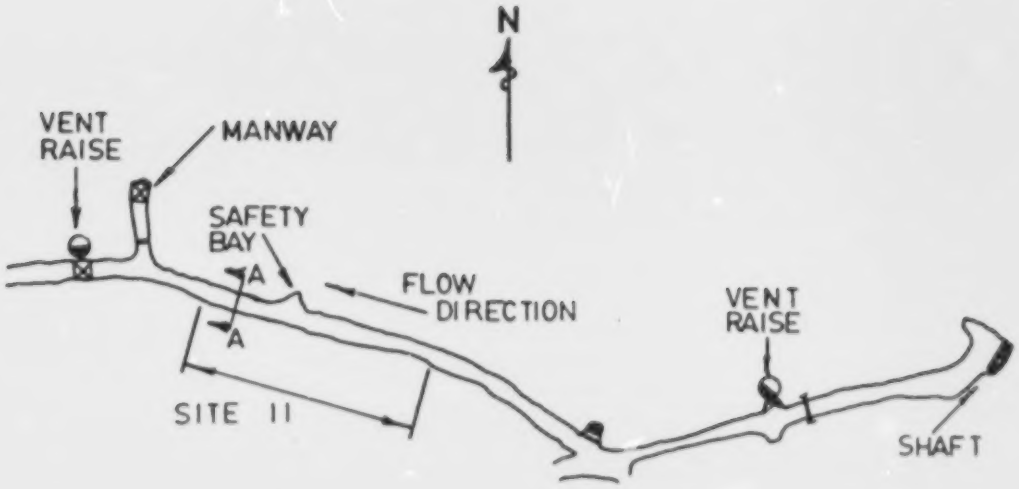
ε = 0.3 - 0.5 m (gunited surface)

3.11 Test Location 11: Camflo Malartic Mine

Site 11 was located within the underground operations of Camflo Malartic Mine at Malartic, Quebec, along the 4-1-W fresh airway. The airway was tracked and very dry with an estimated roughness of 0.3 m to 0.5 m. The section was 42.7 m in length, with about 6 m of diorite at the upstream end, followed by a mixture of sediments and conglomerate rock types. Lengths of one-inch and 2-inch pipe were hung on racks along the section. The average cross sectional area was 6.6 m^2, (about 2.4 m x 2.7 m). The section was 12.8 m downstream from a slight curve and 43.3 m downstream from a 40^o curve. The fresh air vent raise supplying the level was 30 m further upstream from the latter curve. The downstream station was located 9 m from a bulkheaded manway and 15 m upstream from a vent raise supplying the lower levels. Figure 15 shows a typical cross section and a plan view of the site, and Figure 16 shows the variablity.

3.12 Test Locations 12 and 13: Kidd Creek Mine

Test locations 12 through 14 were located at Kidd Creek Mines Ltd. at Timmins, Ontario. Sites 12 and 13 were located along the portal-to-800 ramp. The well-graded roadway was wet with finely crushed rock, and had a -9.6% grade to the downstream direction. Both sites were located on straight sections between sub-levels, where significant leakage occurred through the bulkheads to the open pit breakthroughs. The rock type was basaltic andesite with an estimated roughness of 0.2 m to 0.3 m. Electrical cables, two 6-inch pipes and a one-inch pipe were the only obstructions. Site 12 was 121.9 m long with 30.5 m and 16.2 m of uniform length upstream and downstream, respectively, where bulkeaded sub-level openings connected with the ramp. Site 13 was 143.3 m in length with 26.5 m of uniform length upsteam to the sub-level junction and 3.7 m downstream to another sub-level junction. Each site had an average cross sectional area of 20 m^2



SCALE 1 : 1200

SECTION A-A

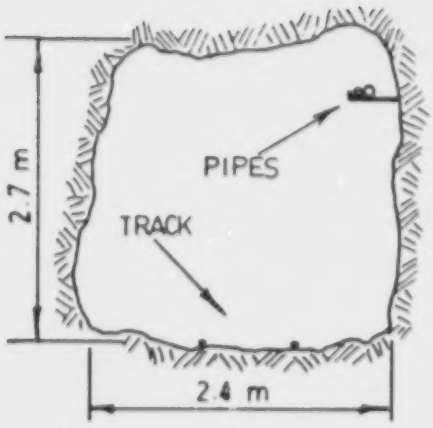


FIGURE 15: TEST SITE 11: CAMFLO MALARTIC MINE

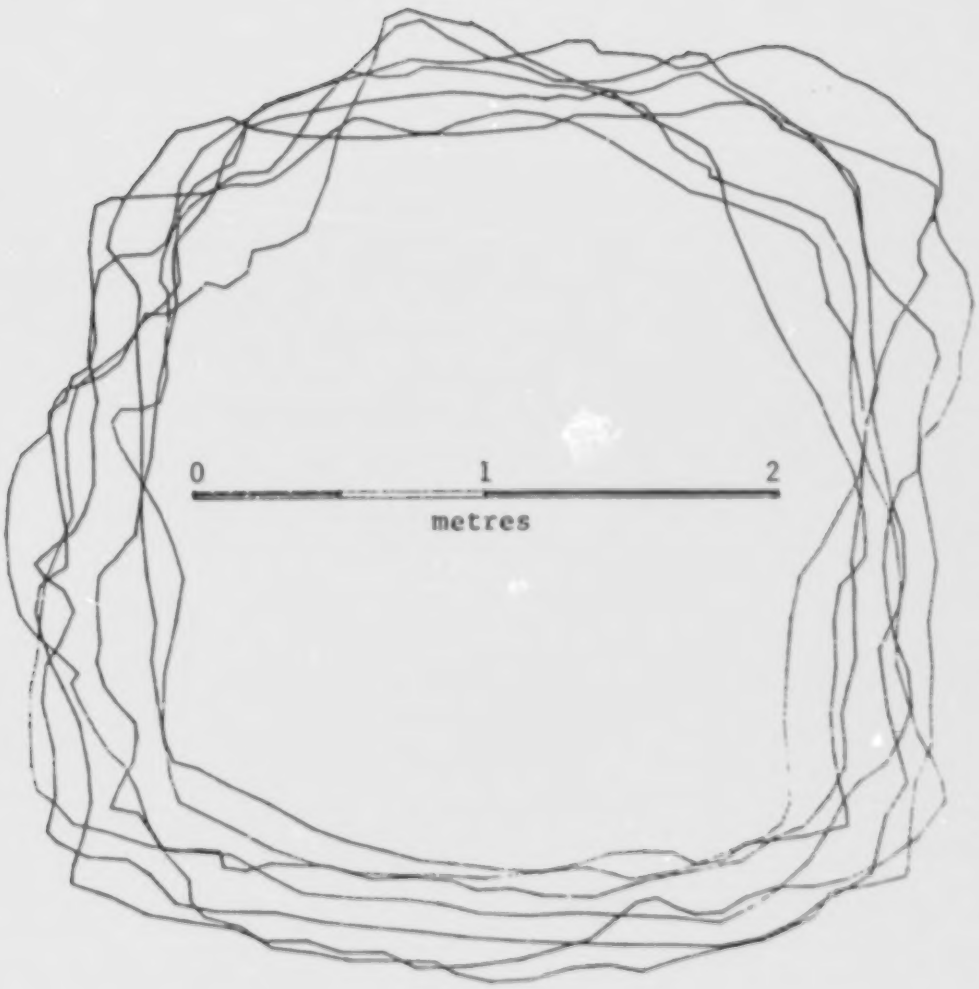


FIGURE 16: VARIABILITY OF TEST SITE 11

TABLE 12

DATA SUMMARY - TEST SITE 11

MINE: Camflo Malartic LOCATION: 4-1-W drift

ROCK/SURFACE TYPE: Sediments and conglomerate

LENGTH: 42.7 m NOMINAL SIZE: 2.4 x 2.7 (m)

PRESSURE DROP: 18.04 Pa AIR DENSITY: 1.200 kg/m^3

Section m	Perimeter m	Area m^2	Velocity m/s	Flow m^3/s
(A) *		6.500	(A) 5.666	36.829
0	8.806	5.336	(A) 5.662	36.803
6.1	8.762	5.200	(A) 5.560	36.140
12.2	10.619	7.517	(B) 6.474	32.208
18.3	10.846	7.713	(B) 6.190	30.795
27.1	9.503	6.108	(B) 6.201	30.850
30.5	10.018	6.849		
36.6	10.832	7.674		
42.7	9.993	6.473		
(B) *		4.975		
Mean	9.935	6.609		33.938

* Section not included in test length

K (Local density) = 0.01066 kg/m^3

K (Standard density) = 0.01066 kg/m^3

K (Dimensionless) = 0.00888

K (Old units) = 58

ε = 0.3 - 0.5 m (uncoated, rock surface)

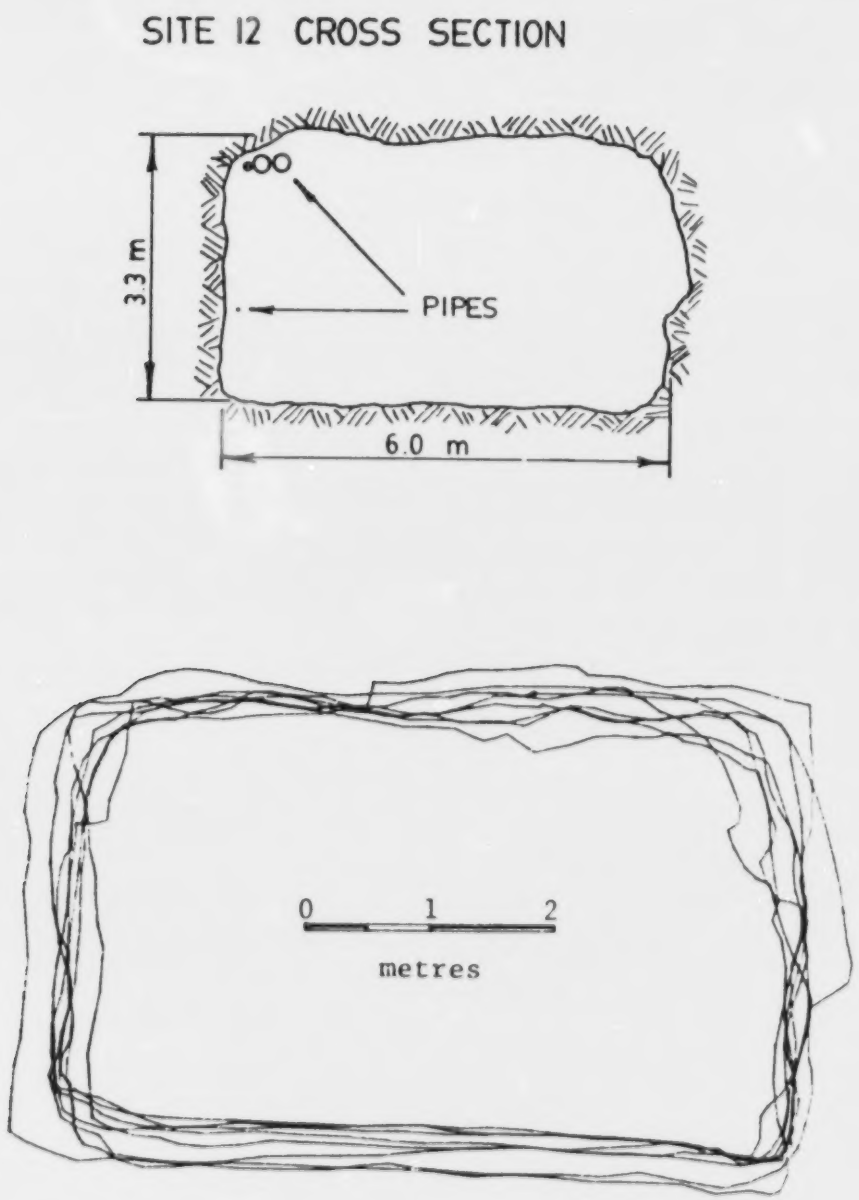


FIGURE 17: LAYOUT AND VARIABILITY OF TEST SITE 12: KIDD CREEK MINE

TABLE 13

DATA SUMMARY - TEST SITE 12

MINE: Kidd Creek LOCATION: Portal - 800 Ramp

ROCK/SURFACE TYPE: Andesite (Basaltic)

LENGTH: 121.9 m NOMINAL SIZE: 6.0 x 3.3 (m)

PRESSURE DROP: 6.92 Pa AIR DENSITY: 1.224 kg/m^3

Section m	Perimeter m	Area m^2	Velocity m/s	Flow m^3/s
(A) *		16.759	(A) 3.39	56.813
0	17.622	18.716	(A) 3.39	56.813
15.2	17.451	18.396	(A) 2.97	49.774
30.5	17.979	19.016	(B) 2.50	58.110
45.7	18.813	21.734	(B) 2.48	57.645
61.0	18.001	20.048	(B) 2.45	56.948
76.2	19.449	23.751	(B) 2.63	61.132
91.5	17.428	18.632		
106.7	17.797	19.335		
121.9	18.360	21.202		
(B) *		23.244		
Mean	18.060	20.096		56.748

* Section not included in test length

K (Local density) = 0.00792 kg/m^3

K (Standard density) = 0.00776 kg/m^3

K (Dimensionless) = 0.00647

K (Old units) = 42

ε = 0.2 - 0.3 m (uncoated, rock surface)

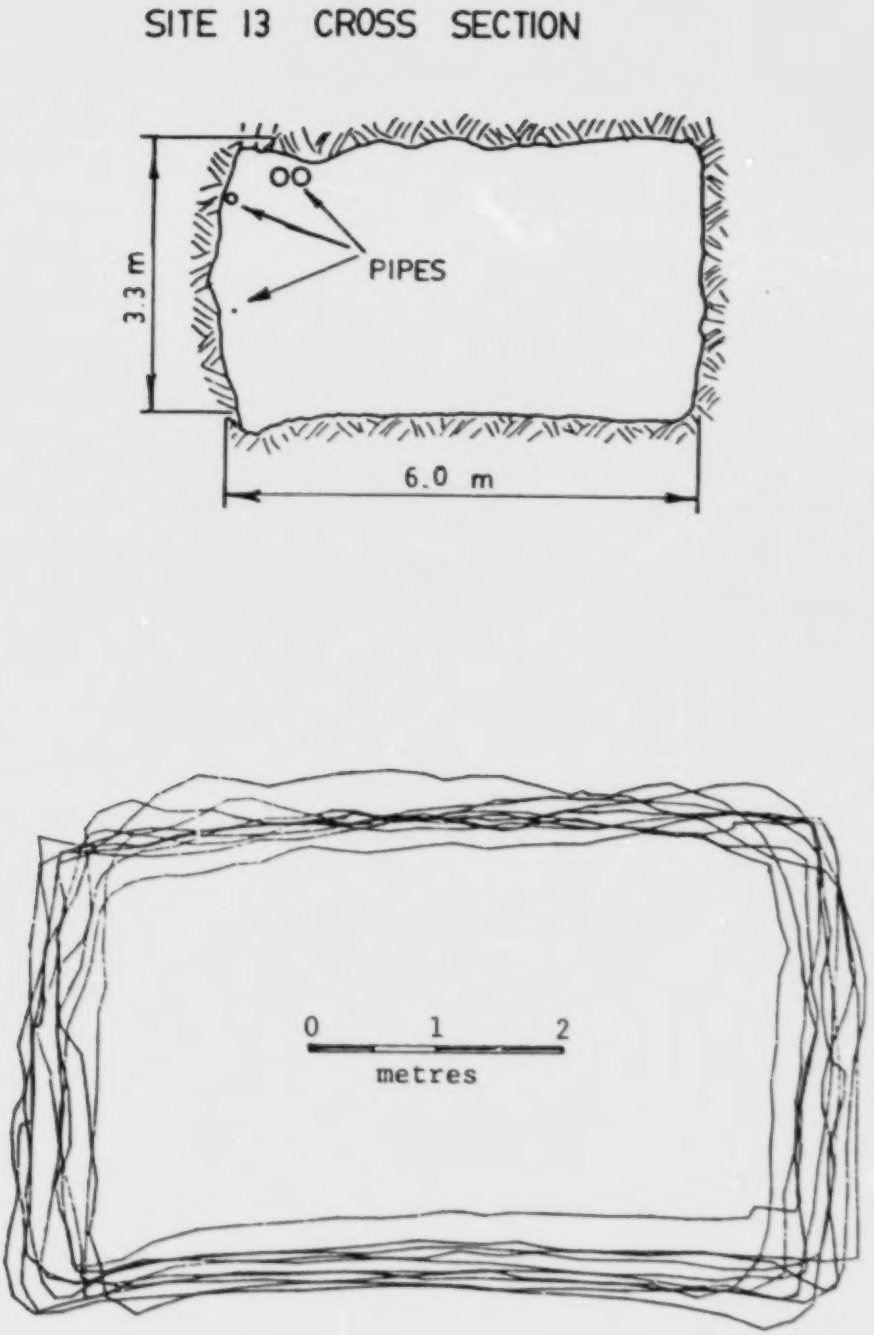


FIGURE 18: LAYOUT AND VARIABILITY OF TEST SITE 13: KIDD CREEK MINE

TABLE 14

DATA SUMMARY - TEST SITE 13

MINE: Kidd Creek LOCATION: Portal - 800 Ramp

ROCK/SURFACE TYPE: Andesite (Basaltic)

LENGTH: 143.3 m NOMINAL SIZE: 6.0 x 3.3 (m)

PRESSURE DROP: 8.0 Pa AIR DENSITY: 1.220 kg/m^3

Section m	Perimeter m	Area m^2	Velocity m/s	Flow m^3/s
(A) *		22.409	(A) 2.46	55.126
0	18.055	19.771	(A) 2.41	54.006
15.2	16.941	16.095	(A) 2.40	53.782
30.5	19.455	21.057	(A) 2.51	56.247
45.7	18.508	20.200	(B) 2.74	49.616
61.0	20.426	23.572	(B) 2.79	50.521
76.2	17.247	18.426	(B) 2.92	52.875
91.5	19.357	20.797		
106.7	18.811	20.733		
121.9	19.556	22.730		
137.2	17.906	19.460		
143.3	18.165	18.565		
(B) *		18.108		
Mean	18.584	20.128		53.168

* Section not included in test length

K (Local density) = 0.00867 kg/m^3

K (Standard density) = 0.00852 kg/m^3

K (Dimensionless) = 0.00710

K (Old units) = 46

ε = 0.2 - 0.3 m (uncoated, rock surface)

and Figures 17 and 18 show typical cross sections and variability of these sites.

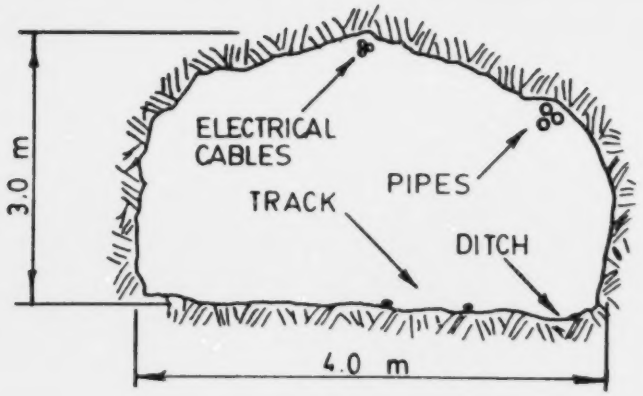
3.13 Test Location 14: Kidd Creek Mine

Test location 14 was located on the 28-35, No. 2 shaft cross cut at Kidd Creek Mines Ltd. The ditched travelway was mainly concrete, surrounding one line of track, with some loose rock on the floor. The walls and back were dacite (mafic flows) with an estimated roughness of 0.3 m. Three 3-inch pipes and electrical cables ran the length of the drift, along the shoulder and down the centre, respectively. The upstream end of the section was 14.0 m downstream from a junction. Another junction was located 7.6 m downstream of the test section which was 91.4 m in length. There was a major obstruction in this test section in the form of a concrete door frame of larger cross sectional area than the average of 12.1 m^2. Figure 19 shows the door frame assembly and a typical drift cross section, while Figure 20 illustrates the variability, including the relative size of the doorway.

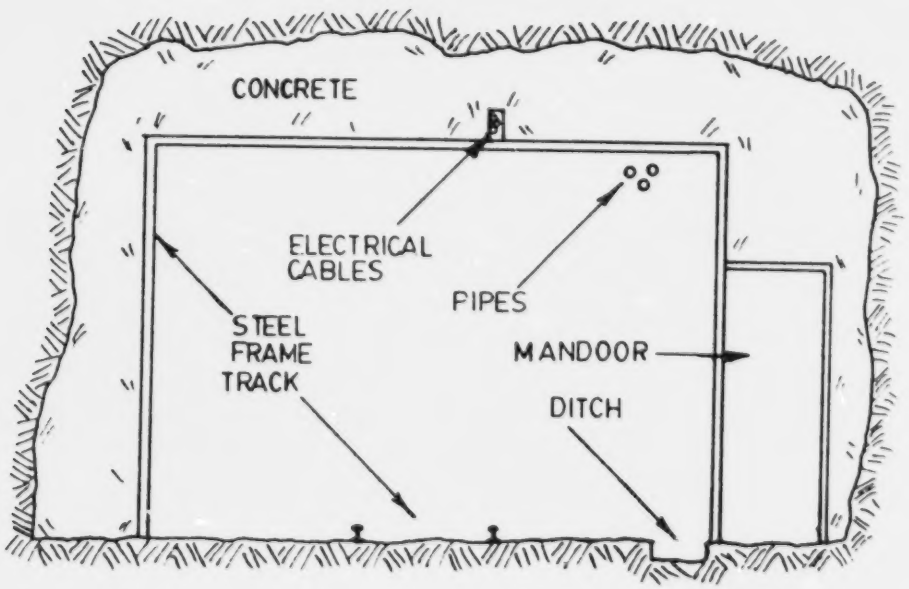
3.14 Test Location 15: Dome Mine

The 1603 haulage drift of Dome Mine was the site for test loctions 15 and 16. Site 15 was located between No. 6 shaft and No. 8 shaft on the 16th level. The traveling surface was dry, hard-packed mud surrounding the track, while the ditch was partially water filled. The walls and back were massive volcanics made up of andesite and acite with an estimated roughness of 0.20 m to 0.25 m. The 110.9 m length included one safety bay and had 6.1 m of uniform length upstream to bulkheaded drifts. The bulkheads were constructed flush with the drift walls, thus causing little obstruction to air flow. At 11 m beyond the downstream station, there was a junction with a small drift for an ore pass and water dam. Obstructions, running the length of the site, included electrical cable racks and a trolley

SITE 14 CROSS SECTION



DOOR FRAME ASSEMBLY



SCALE 1:50

FIGURE 19: TEST SITE 14: KIDD CREEK MINE, 28-35 CROSS CUT

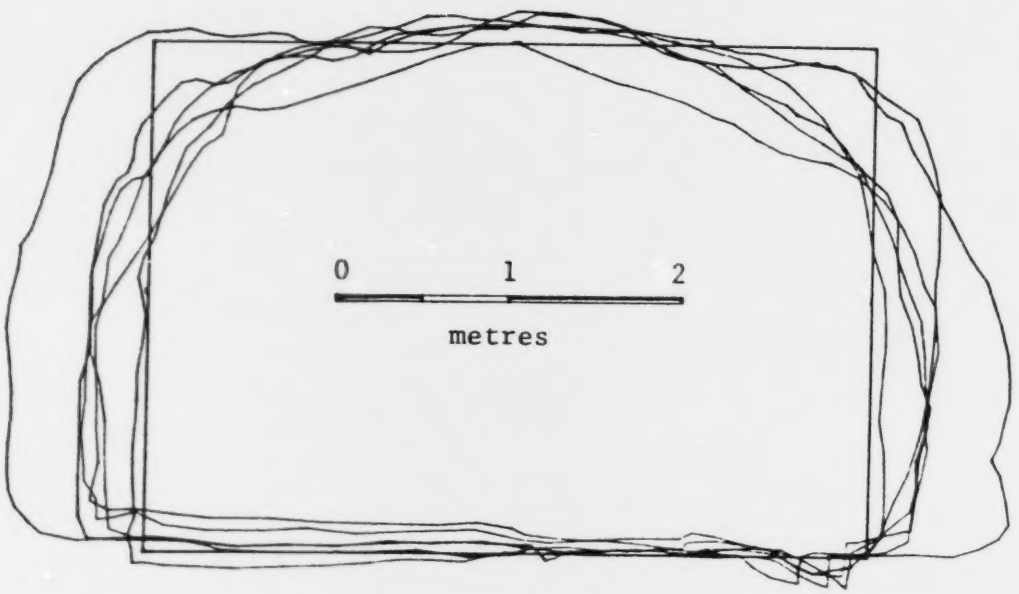


FIGURE 20: VARIABILITY OF TEST SITE 14

TABLE 15

DATA SUMMARY - TEST SITE 14

MINE: Kidd Creek LOCATION: 28 - 35 Cross-cut

ROCK/SURFACE TYPE: Dacite (Mafic flows)

LENGTH: 91.4 m NOMINAL SIZE: 4.0 x 3.0 (m)

PRESSURE DROP: 13.27 Pa AIR DENSITY: 1.286 kg/m^3

Section m	Perimeter m	Area m	Velocity m/s	Flow m /s
(A) *		10.308	(A) 3.86	39.789
0	13.341	12.064	(A) 3.89	40.098
15.2	13.676	12.064	(B) 3.85	50.512
30.5	15.888	15.080	(B) 3.74	49.069
45.7	13.452	11.292	(B) 3.74	49.069
61.0	14.268	13.010	(B) 3.46	45.395
76.2	13.521	11.553	(B) 3.58	46.976
91.4	13.730	11.706		
(B) *		13.120		
Mean	13.982	12.312		45.843

* Section not included in test length

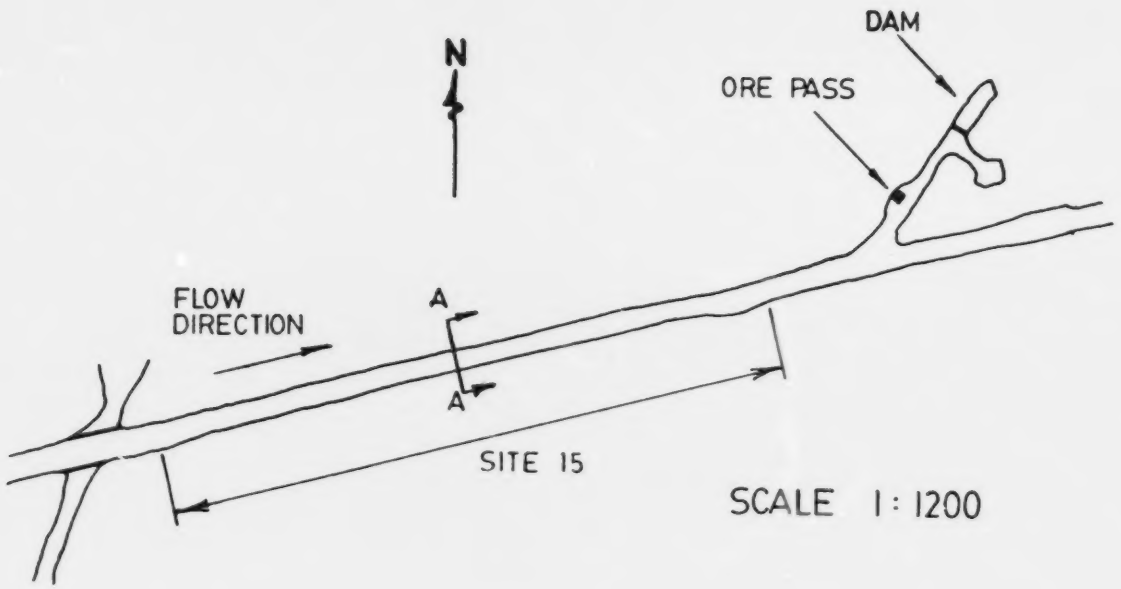
K (Local density) = 0.00922 kg/m^3

K (Standard density) = 0.00860 kg/m^3

K (Dimensionless) = 0.00717

K (Old units) = 46

= 0.3 (uncoated, rock surface)



SECTION A-A

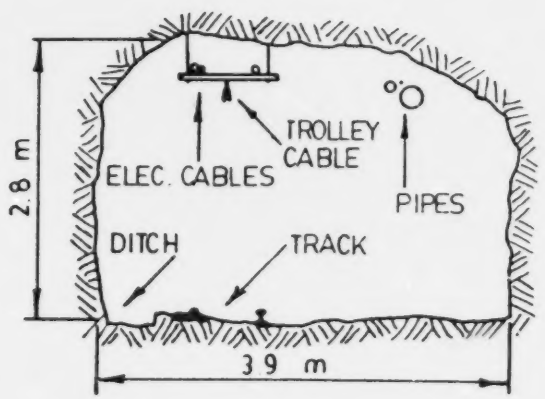


FIGURE 21: TEST SITE 15: DOME MINE, 16th LEVEL

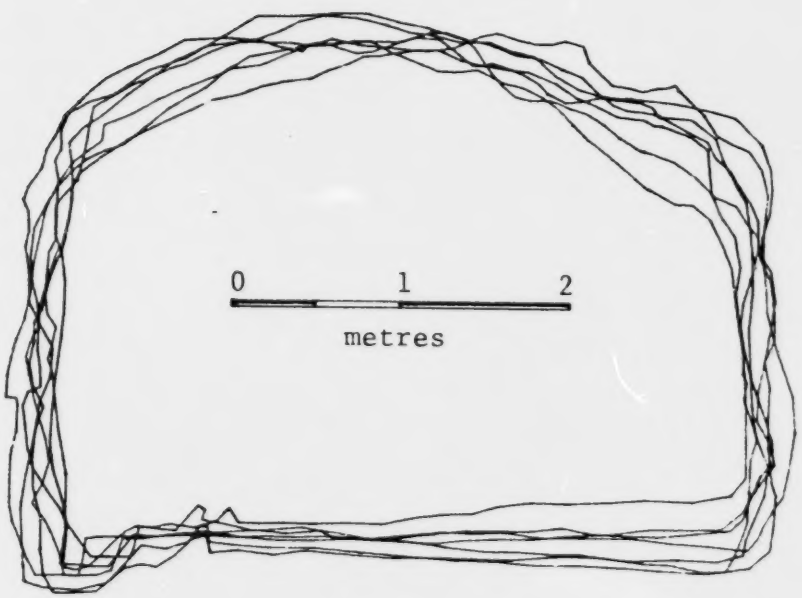


FIGURE 22: VARIABILITY OF TEST SITE 15

TABLE 16

DATA SUMMARY - TEST SITE 15

MINE: Dome LOCATION: 1603 Haulage

ROCK/SURFACE TYPE: Andesite, Dacite (Massive volcanics)

LENGTH: 110.9 m NOMINAL SIZE: 3.9 X 2.8 (m)

PRESSURE DROP: 13.81 Pa AIR DENSITY: 1.255 kg/m^3

Section m	Perimeter m	Area m^2	Velocity m/s	Flow m^3/s
(A) *		10.918	(A) 2.82	30.789
0	13.055	10.706	(A) 2.82	30.789
15.2	13.857	11.525	(A) 3.02	32.972
30.5	12.339	9.547	(A) 3.10	33.846
45.7	13.195	10.735	(B) 2.78	30.422
61.0	13.728	11.879	(B) 2.81	30.750
76.2	12.639	9.676	(B) 2.89	31.625
91.4	14.275	12.260	(B) 2.84	31.078
110.9	14.261	12.152		
(B) *		10.943		
Mean	13.419	11.066		31.534

* Section not included in test length

K (Local density) = 0.01265 kg/m^3

K (Standard density) = 0.01209 kg/m^3

K (Dimensionless) = 0.01008

K (Old units) = 65

ε = 0.2 - 0.25 m (uncoated, rock surface)

cable assembly hanging from the back and one-inch, 4-inch and 12-inch pipes. Figures 21 and 22 show a typical cross section and plan view of the location and the variability.

3.15 Test Location 16: Dome Mine

Upstream from site 15 and beyond No. 8 shaft at Dome, was the location of site 16. This site was within a highly sheared zone of flow breccia which yielded some very smooth faces as well as some very blocky ground, depending on the shear orientation. Average wall roughness was usually estimated at 0.23 m - 0.30 m. The travelway was hard-packed dirt surrounding the single line of track and the parallel ditch was relatively dry. One large safety bay was located at the halfway point of the 127.1 m section and there were junctions located 21.3 m from the upstream station and 32.9 m from the downstream station. The average cross sectional area of 11.9 m^2 was occupied by numerous pipes hung on a rack at the shoulder and electric and trolley cables hung from the back in the centre of the drift. A typical cross section and the variability are shown in Figure 23.

3.16 Test Location 17: Central Canada Potash

Test section 17 was located south of the No. 1 shaft at Central Canada Potash, a wholly owned subsidiary of Noranda Mines Ltd., in the Colonsay area, 64 km east of Saskatoon, Saskatchewan.

The chief problem at this mine was the low air velocity. Although section 17 was relatively short (61 m) it had a higher velocity than any other part of the mine. The 61.0 m section was heavily dusted throughout and dipped slightly to the west. The back was bolted with wood block seated bolts on either side of a 0.3 m wide destress slot, cut to a depth of 2.4 m to 3.0 m vertically into the back. Large irregularities in the section were due to elastoplastic flow of the rock material and

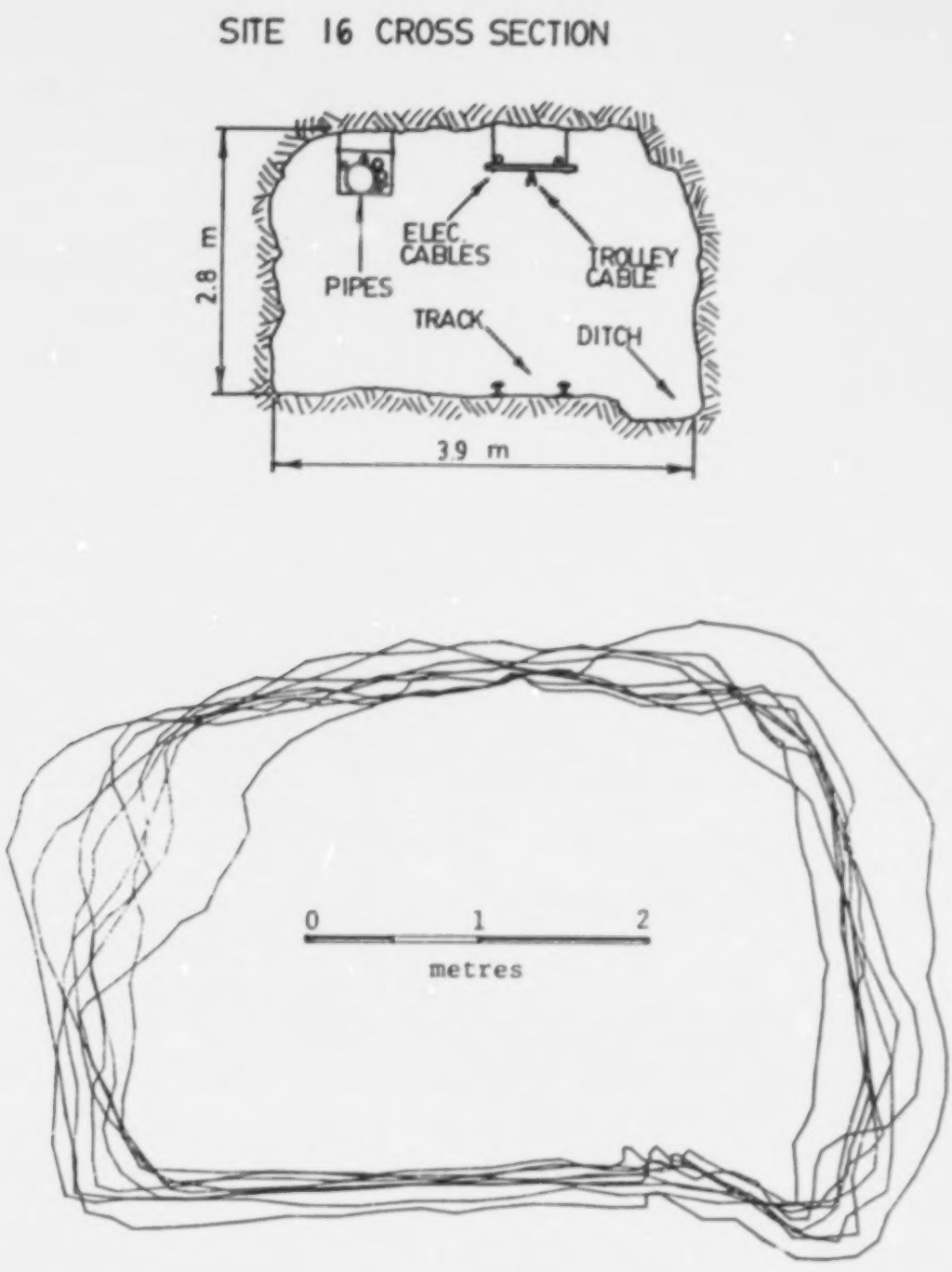


FIGURE 23: LAYOUT AND VARIABILITY OF TEST SITE 16: DOME MINE, 16th LEVEL

TABLE 17

DATA SUMMARY - TEST SITE 16

MINE: Dome LOCATION: 1603 Haulage

ROCK/SURFACE TYPE: Flow Breccia (Mafic flows)

LENGTH: 127.1 m NOMINAL SIZE: 3.9 X 2.8 (m)

PRESSURE DROP: 18.65 Pa AIR DENSITY: 1.253 kg/m^3

Section m	Perimeter m	Area m^2	Velocity m/s	Flow m^3/s
(A) *		10.720	(A) 3.76	40.307
0	13.044	10.520	(A) 3.76	40.307
15.2	13.710	11.695	(A) 3.71	39.771
30.5	14.777	13.159	(A) 3.68	39.450
45.7	13.756	11.641	(B) 4.07	40.965
61.0	13.146	10.687	(B) 4.04	40.663
76.2	14.084	12.297	(B) 4.10	41.267
91.4	14.132	12.386	(B) 4.04	40.663
106.6	14.006	11.765		
121.9	15.742	15.356		
127.1	15.076	12.717		
(B) *		10.065		
Mean	14.147	12.223		40.424

* Section not included in test length

K (Local density) = 0.01159 kg/m^3

K (Standard density) = 0.01110 kg/m^3

K (Dimensionless) = 0.00925

K (Old units) = 60

c = 0.23 - 0.30 m (uncoated, rock surface)

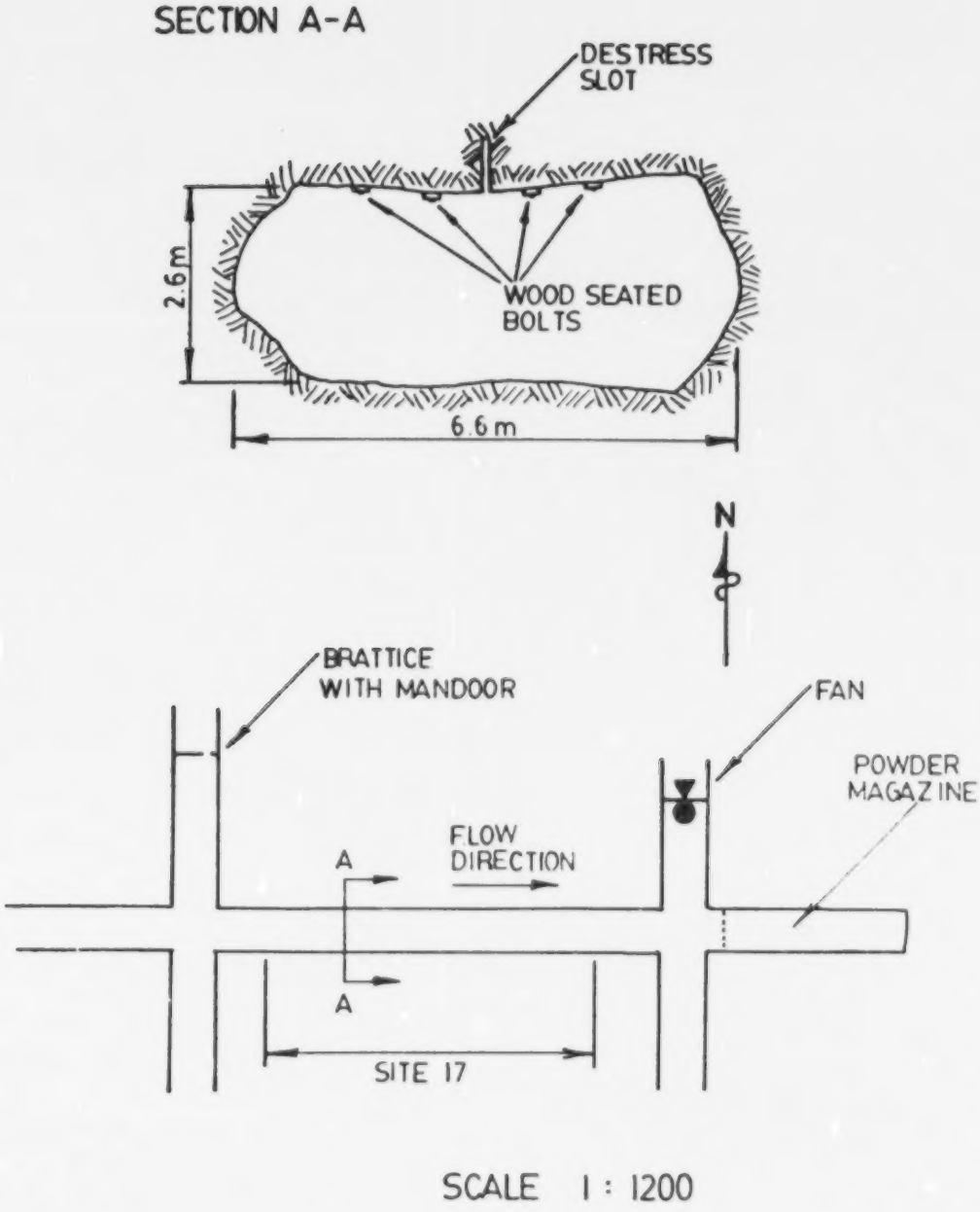


FIGURE 24: TEST SITE 17: CENTRAL CANADA POTASH

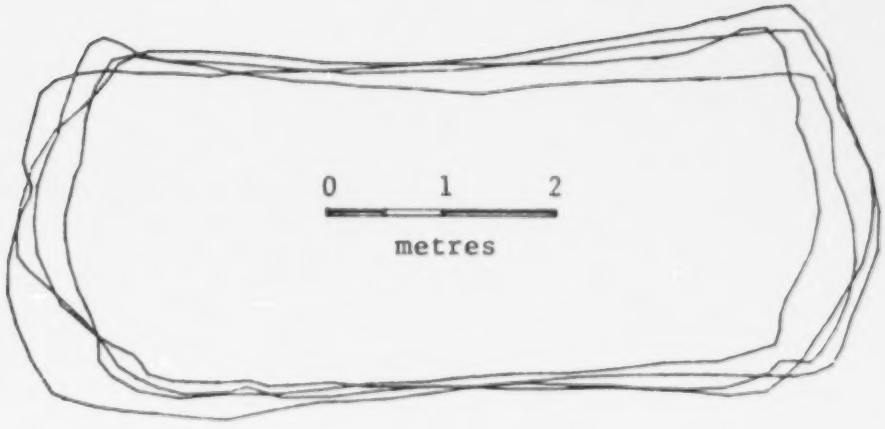


FIGURE 25: VARIABILITY OF TEST SITE 17

TABLE 18

DATA SUMMARY - TEST SITE 17

MINE: Central Canada Potash LOCATION: #1 Shaft Area

ROCK/SURFACE TYPE: Potash

LENGTH: 61.0 m NOMINAL SIZE: 6.6 x 2.6 (m)

PRESSURE DROP: 1.65 Pa AIR DENSITY: 1.217 kg/m^3

Section m	Perimeter m	Area m^2	Velocity m/s	Flow m^3/s
(A) *		16.968	(A) 1.96	33.257
0	18.466	19.129	(B) 2.31	39.215
15.2	19.504	20.704		
45.7	18.140	17.470		
61.0	16.916	16.572		
30.5(B)	17.331	16.976		
Mean	18.071	18.170		36.235

* Section not included in test length

K (Local density) = 0.00684 kg/m^3

K (Standard density) = 0.00674 kg/m^3

K (Dimensionless) = 0.00562

K (Old units) = 36

ε = 0.06 - 0.09 m (smooth surface, uncoated)

inconsistent trimming by the mechanical equipment. Average wall rougness was visually determined at 0.06 m - 0.09 m. The average cross sectional area was 17.8 m^2. Intersections were located 9.1 m from the upstream station and 3.0 m from the downstream station. Figures 24 and 25 show the layout and variability of the area.

3.17 Test Locations 18 and 19: Central Canada Potash

The West 4 North 12 fresh air intake drift at Central Canada Potash, was the site for locations 18 and 19. As shown in Figure 26, there were four parallel entries, inter-connected by cross-cuts on 60 m centres. Two of the entries were used for intake air and were separated from the return air entries by bulkheads. The bulkheads were constructed of concrete blocks and potash waste had been piled against them and wetted down to make an effective seal. Foam sealant had been used to seal the joint between the tops of the blocks and the roof rock.

Because of the low velocities, it was necessary to make the test sections as long as possible. The selected sites included four cross-cuts. The bulkheads within the section were carefully inspected and there were no detectable leaks. Most of the air travelled down one of the parallel intakes as the other was used as a storage area. No cross-currents could be detected at the four cross-cuts connecting the parallel intakes.

Sections 18 and 19 were designed to include the same number of cross-cuts but different lengths of rock surface in an attempt to isolate the effect of the cross-cuts. The general layout is shown in Figure 26. Being machine cut, the cross section was very regular, although the superimposed profiles (shown in Figure 27) do indicate some variability, probably due to differential plastic deformation of the opening.

Section 18 was 268.2 m long, with 237.1 m of rock surface

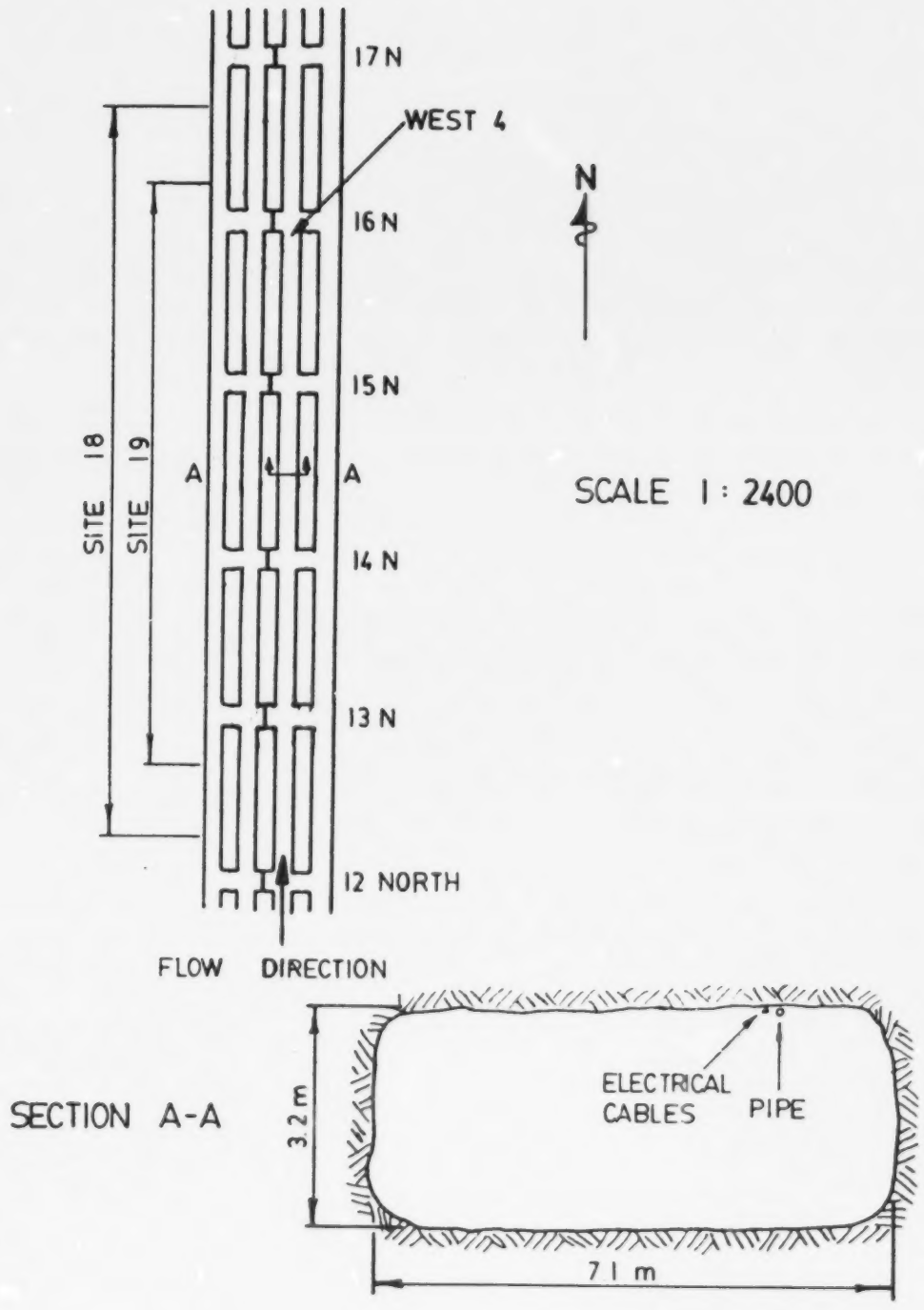


FIGURE 26: TEST SITES 18 & 19: CENTRAL CANADA POTASH

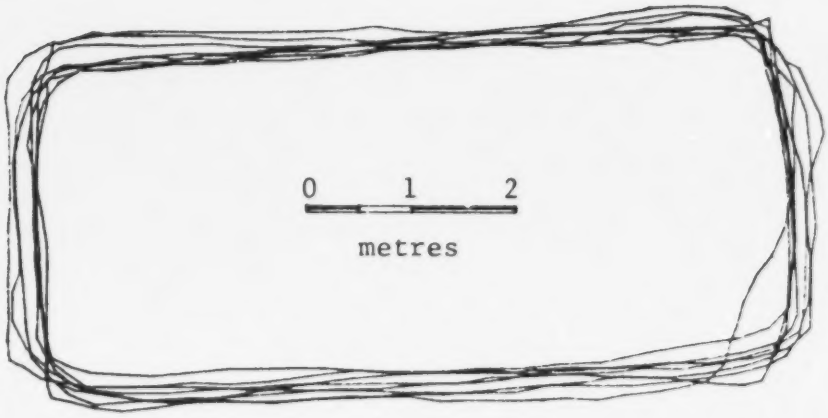


FIGURE 27: VARIABILITY OF TEST SITES 18 AND 19

TABLE 19

DATA SUMMARY - TEST SITE 18

MINE: Central Canada Potash LOCATION: 4W 12N

ROCK/SURFACE TYPE: Potash

LENGTH: 268.2 m NOMINAL SIZE: 7.1 x 3.2 (m)

PRESSURE DROP: 5.34 Pa AIR DENSITY: 1.217 kg/m^3

Section m	Perimeter m	Area m	Velocity m/s	Flow m /s
0 (A)	19.591	22.409	(A) 2.115	47.395
30.5	19.889	22.400	(A) 2.120	47.507
61.0	20.712	24.628	(B) 2.246	51.734
91.4	19.716	21.690	(B) 2.389	55.028
152.4	20.137	23.066		
182.8	20.166	23.322		
213.4	19.336	20.910		
243.8	20.680	25.837		
(B) *		23.034		
Mean	20.059	23.072		50.416

* Section not included in test length

K (Local density) = 0.00479 kg/m^3

K (Standard density) = 0.00473 kg/m^3

K (Dimensionless) = 0.00394

K (Old units) = 26

= 0.06 - 0.09 m (smooth, uncoated surface)

TABLE 20

DATA SUMMARY - TEST SITE 19

MINE: Central Canada Potash LOCATION: 4W 12N

ROCK/SURFACE TYPE: Potash

LENGTH: 213.4 m NOMINAL SIZE: 7.1 x 3.2 (m)

PRESSURE DROP: 4.76 Pa AIR DENSITY: 1.217 kg/m^3

Section m	Perimeter m	Area m^2	Velocity m/s	Flow m^3/s
(A) *		22.409	(A) 2.169	48.605
0	19.591	22.409	(A) 1.993	44.661
30.5	19.889	22.400	(B) 2.420	55.742
61.0	20.712	24.628		
121.9	20.225	23.850		
152.4	20.137	23.066		
182.8	20.166	23.322		
213.4	19.366	20.910		
(B) *		23.034		
Mean	20.060	23.083		49.669

* Section not included in test length

K (Local density) = 0.00556 kg/m^3

K (Standard density) = 0.00548 kg/m^3

K (Dimensionless) = 0.00457

K (Old units) = 30

ε = 0.06 - 0.09 m (smooth, uncoated surface)

and 31.1 m occupied by the four cross-cuts, while section 19 contained the same cross-cuts but only 182.3 m of rock surface. The sawtooth shape on the walls due to the cutting machine gives a roughness of about 0.06 m to 0.09 m with a cutter pass interval, measured along the drift, of 0.35 m to 0.40 m. The roadway was hard and slick while the back had an estimated roughness of less than 0.6 cm. A length of electrical cable and a 4-inch pipe length occupies the drift.

3.18 Test Location 20: Prince Mine

Test location 20 was located at the Prince Mine, an underground coal operation of the Cape Breton Development Corporation. A test site was chosen in the 3D fresh air intake, which was steel arched on 0.9 m centers with corrugated steel backing. The 1.3 cm-deep corrugations were parallel to the flow direction and the steel sets were 8.9 cm deep. The section was very regular with slight necking near the upstream station. The base of the arch was 5.2 m across, and the height of the arch was 3.5 m giving an average area of 14.4 m^2. Figure 28 shows a typical cross section. Double track with exposed ties ran for the most part of the 103.6 m length and the upstream and downstream stations had 15.2 m and 9.1 m of uniform length beyond each station, upstream and downstream respectively.

3.19 Test Location 21: Lingan Mine

Site 21 was located along the 4D main rake trip and fresh air intake, at the Lingan Mine, another subsidiary of the Cape Breton Development Corporation.

The site had 10 cm deep steel arch sets on 0.9 m centers with round timber lagging at the back between sets, occupying one third of the arch perimeter, and corrugated steel along the walls, occupying the remaining two thirds. Figure 29 shows a typical cross section. The site had a grade of about -10%

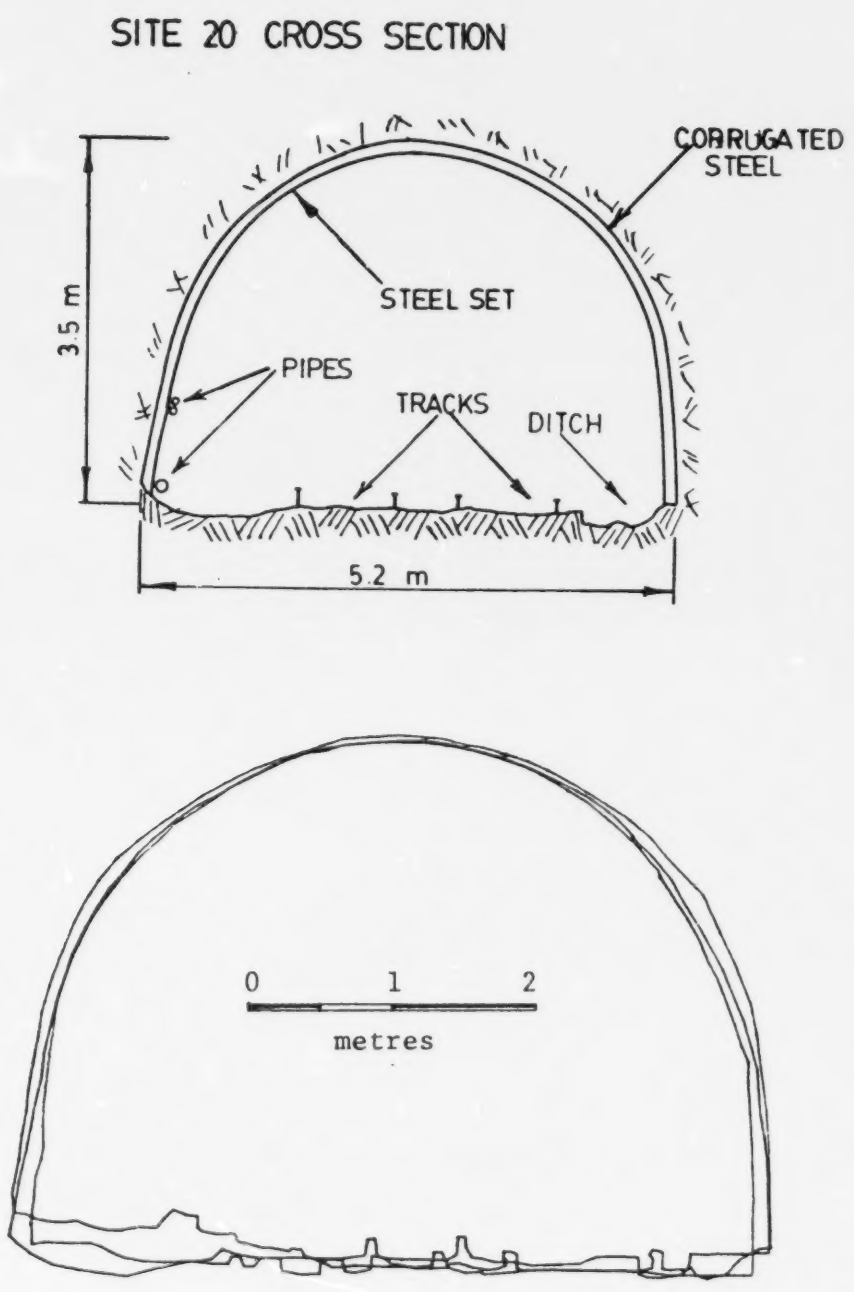


FIGURE 28: LAYOUT AND VARIABILITY OF TEST SITE 20: PRINCE MINE

TABLE 21

DATA SUMMARY - TEST SITE 20

MINE: Prince Mine (Devco) LOCATION: 3D Fresh Air Intake

ROCK/SURFACE TYPE: Steel arches with corrugated sheeting

LENGTH: 103.6 m NOMINAL SIZE: 5.2 x 3.5 (m)

PRESSURE DROP: 5.71 Pa AIR DENSITY: 1.246 kg/m^3

Section m	Perimeter m	Area m	Velocity m/s	Flow m /s
(A) *		14.657	(A) 2.072	30.366
61.0	15.887	14.397	(A) 2.170	31.806
(B) *		14.464	(B) 2.098	30.348
			(B) 2.129	30.795
Mean	15.887	14.397		30.829

* Section not included in test length

K (Local density) = 0.01090 kg/m^3

K (Standard density) = 0.01050 kg/m^3

K (Dimensionless) = 0.00875

K (Old units) = 56

= 0.09 m (corrugated sheeting, steel arch sets)

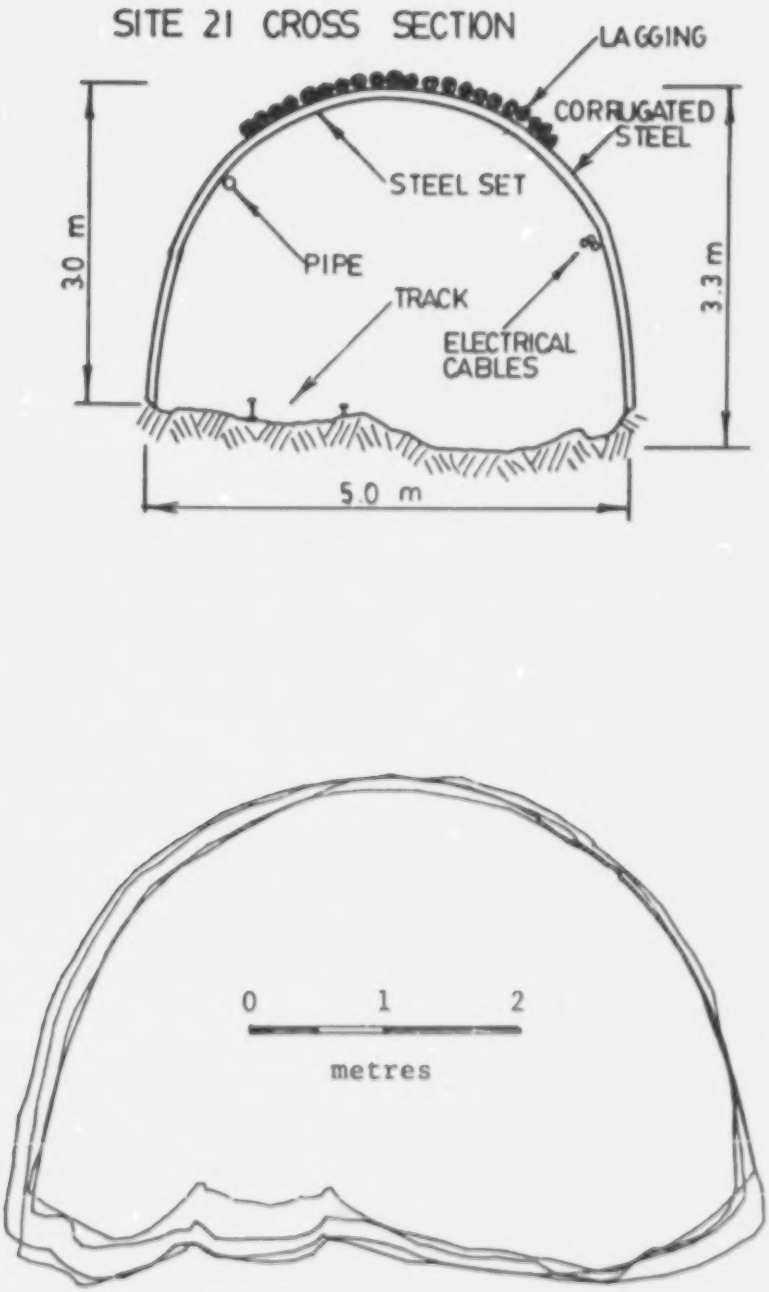


FIGURE 29: LAYOUT AND VARIABILITY OF TEST SITE 21: LINGAN MINE

TABLE 22

DATA SUMMARY - TEST SITE 21

MINE: Lingan Mine (Devco) LOCATION: 4D Main Rake Trip

ROCK/SURFACE TYPE: Steel arches with corrugated sheeting

LENGTH: 78.3 m NOMINAL SIZE: 5.0 x 3.0 (m)

PRESSURE DROP: 26.28 Pa AIR DENSITY: 1.248 kg/m^3

Section m	Perimeter m	Area m	Velocity m/s	Flow m /s
(A) * 57.9 (B) *	14.831	15.491 13.538 13.307	(A) 4.394 (A) 4.191 (A) 4.327 (B) 4.977 (B) 4.994	68.061 64.921 67.034 66.233 66.462
Mean	14.831	13.538		66.542

* Section not included in test length

K (Local density) = 0.01270 kg/m^3

K (Standard density) = 0.01221 kg/m^3

K (Dimensionless) = 0.01017

K (Old units) = 66

= 0.10 m (corrugated sheeting, steel arch sets)

downstream and the track was elevated 0.3 m above the muddy travelling surface. The test section was 78.3 m in length with 30.5 m and 9.1 m of uniform length above and below the upstream and downstream stations respectively. The average area was 13.5 m^2 with 5.0 m across the base of the arch and 3.3 m from the back to the deepest point of the travelling surface.

4.0 DISCUSSION

4.1 Accuracy of Parameters

Even though the average velocity may be determined accurately by taking a large number of readings across the cross-section of the airway, the quantity of air flow depends on the flow area used. The effective area of flow is not necessarily the accurately measured area at the plane where the velocity is measured. The effective flow area seems to be dependent on conditions upstream of the measuring station.

It is well established that the air flow is disturbed for some distance downstream of a bend or an obvious obstruction, and, in this project, velocity measuring stations were carefully selected to ensure that they were well away from the influence of any such disturbances. Nevertheless, at many of the test sites, there was a significant difference in the mean flows measured at the two stations, although consistent measurements were obtained at each individual flow station. For example, at test site 10, three measurements at station A gave a mean flow of 10.5 m^3/s with a standard deviation of 0.12, while three measurements at station B gave a mean flow of 12.5 m^3/s with a standard deviation of 0.11.

Probably the only way to measure airflow accurately is to build a smooth-lined duct of smaller area than the airway and use a converging inlet to minimize tubulence, as described by McElroy and Richardson[1]. However, such an installation is expensive and impractical for most work of this type.

In using the K factor method to compute airway resistances, the implications of precision are worth investigating. Mine openings are often extremely variable in shape, size, surface texture and sinuosity. The purpose of the K

factor is to characterize these variables by a single parameter, such that airway resistance can be calculated by the formula:

$$R = K L C / A^3$$

Multiplying the resistance value by the square of the airflow rate will then give the pressure drop through the airway. The resultant value of pressure drop through a given circuit then defines the fan duty required to move the specified quantity of air through the current.

The airway length, L, can generally be determined quite accurately, but C and A, the perimeter and area, are more difficult to define. Besides contributing to R, A is also significant in the definition of flow rate, Q, since Q = Area x Velocity, and velocity is normally what is measured. Area appears in the resistance equation to the third power, so any error in the value used for A will have an exaggerated effect on the resistance. Since it is evident that, in airways of irregular shape, the airstream does not occupy the total area, accurate determination of effective area is not possible by direct measurement. The photoprofile method, for instance, although giving an accurate measurement of actual area at a particular plane, gives an area larger than that which is effectively available in an irregular airway.

Since the ultimate objective is to get a good estimate of the pressure drop, P, it is instructive to analyze the effect on P of an error in A. For the purpose of the analysis, assume that the error in A for a particular type of airway is +x%, and there is no error in the other parameters. There are various scenarios to examine depending on the method of defining Q, both in the preliminary determination of K factors and in the subsequent use of the K factors to determine P.

First, consider the case where A is used to determine Q

from V. If there is no error in V, the error in Q will be the same as the error in A, +x%. If this value of Q is now used to calculate a K factor, using equations (1) and (2), the error in K will also be +x%. Now, using the K factor to compute pressure drop in other similar airways, if Q is known accurately, the error in P will be -2x%. However, if Q is defined in terms of V and A, with an accurate value of V and the same error of +x% in A, there will be no error in P.

Second, consider the case where Q for the K factor determination is determined accurately without reference to the irregular area. In this case, the error in K will be +3x% or three times the error in A. Provided accurate Q values are used to determine pressure drops in other similar airways, and the error in A is still +x%, the error in K will be compensated and accurate values of P will be obtained. However, if Q is defined as V x A, the error in P will be +2x%.

In practical terms, since, in mine ventilation work, Q is normally measured and dealt with as the product of velocity and area, it would seem appropriate to adopt the normal field measurement procedures for the determination of K factors as in scenario 1 above.

4.2 Mine Design Values

One of the reasons for using K factors, of course, is to estimate pressure requirements for airways in the planning stage. Here, only the nominal dimensions of the airway are available and the character of the surface is unknown. Another approach to this problem is to use standard hydraulic theory and calculate a friction factor from the formula for completely turbulent flow in rough conduits as discussed in Section 2.7 on page 17.

Figure 30 was constructed using equation (3) to illustrate the relationship between the K factors and the airway roughness.

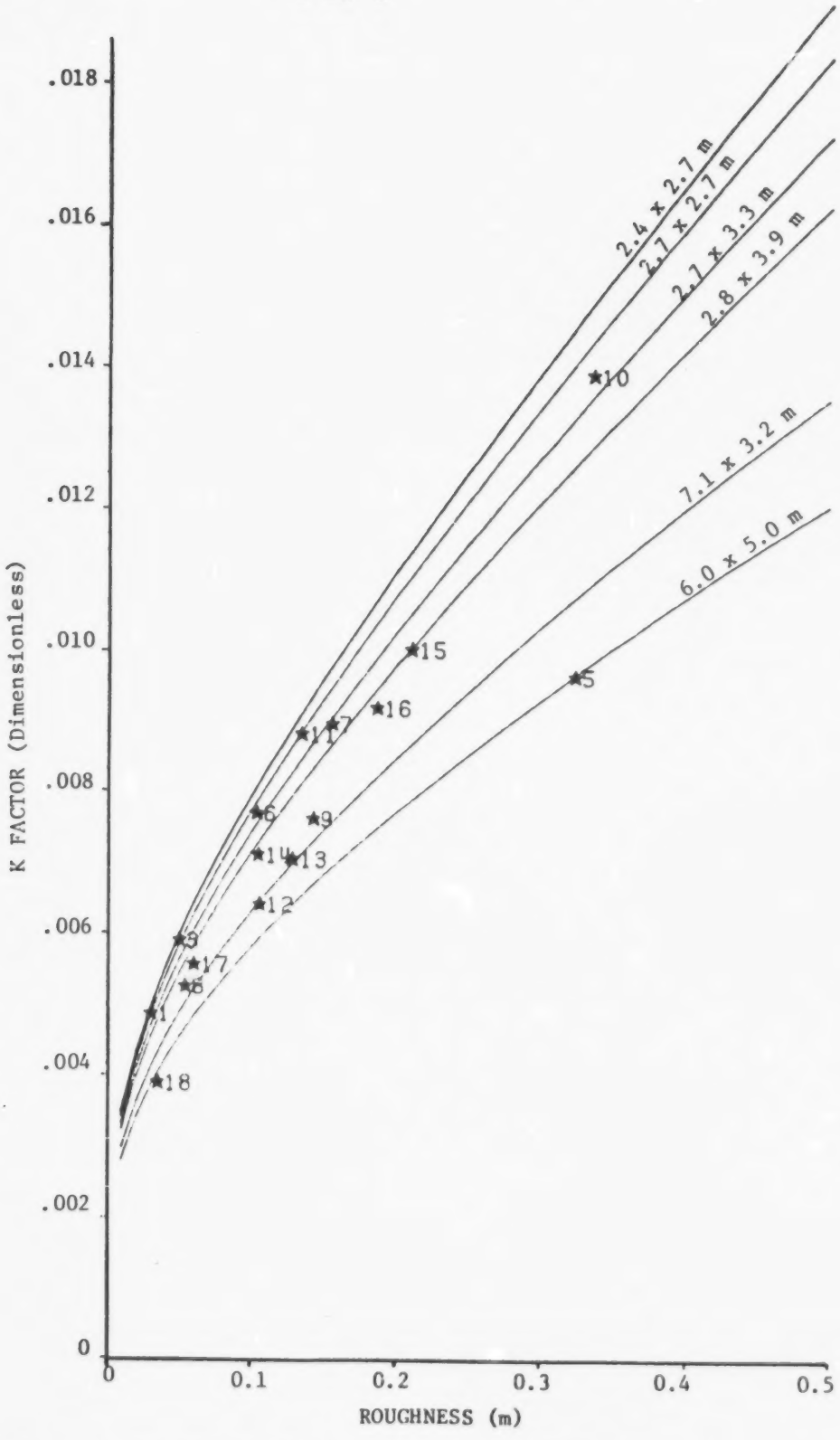


FIGURE 30: RELATIONSHIP BETWEEN K FACTORS AND AIRWAY ROUGHNESS

The lines on the graph are computed from the nominal dimensions of the various airways studied (assuming a rectangular shape), and show how the dimensionless K factor (f/8) varies with the roughness parameter as used in the hydraulic formula. The stars on the graph represent the actual test data from rock airways, and show the roughness values which would correspond to the measured K factors if the K factors were calculated from the hydraulic formula using the measured values of area and perimeter for each airway.

Values of airway roughness visually estimated in the field are generally higher than the values indicated on Figure 30. Except where the roughness is of a regular nature, as in the case of potash for instance, the roughness estimates are very subjective. The tendency is to base the visually estimated roughness value on the maximum difference between peaks and valleys in the rock walls, but perhaps half of this value would be more appropriate.

It was hoped that the photoprofiles, when superimposed, would give a useful means of assessing surface roughness. Since the pictures were taken at 7 - 15 metre intervals however, they only show the general variability in the shape of the airways. Photoprofiles taken at 0.5 m intervals, or less, over a short section of airway might be more suitable to characterize the surface roughness.

5.0 CONCLUSIONS

Systematic evaluation of mine airway friction factor parameters has been performed across a broad array of mining environments and within a range of rock types. Measurements were carried out using standard methods and equipment in reasonably straight and unobstructed airways.

Friction factor values for igneous rock airways were generally found to be lower than the standard published values.

The photoprofile technique for characterizing airway cross-sections is simple and fast in execution but tedious in the data processing stage. Superimposing the pictures gives a good idea of the variability of an airway but does not characterize the surface roughness unless the pictures are taken closely together.

The range of data compiled in this study is not intended to be suitable for application by all mining operations. Due to limitations of time, the number of sites available, and to the variability in airway construction methods at each of the test sites, the data gathered offer only general applicability to many mining operations. The methodology used, however, may be readily adopted by individual operators and used to perform site specific measurements.

Airway friction factors can be adequately derived from standard hydraulic formulae if care is taken not to over-estimate the surface roughness parameter.

It would therefore be reasonable to recommend that further friction factor parameter studies be implemented both to complement the existing data base and to make provision to systematically educate ventilation engineers in the techniques necessary to perform such surveys at individual mine sites.

Owing to restrictions in available research time and communications with sponsor mine sites, only a small fraction of available Canadian mines were able to be investigated during the course of this research project. Should funding become available in future, the principles and techniques developed in this study could be rapidly and successfully applied to other sites, not previously attended.

REFERENCES

1. G.E. MCELROY and A.S. RICHARDSONN, "Resistance of Metal-Mine Airways", U.S.B.M. Bulleting 261, 1927.

2. V.L. STREETER and E.B. WYLIE, "Fluid Mechanics - 7th Edition", McGraw-Hill Book Company, 1979.

APPENDICES

APPENDIX 1

COMPARISON OF SITE CONDITION AND FRICTION FACTOR DATA - PRESENT STUDY VERSUS MCELROY/RICHARDSON STUDY

TABLE A-1

COMPARISON OF FRICTION FACTOR PARAMETERS FOR SELECTED SITE CONDITIONS: PRESENT STUDY VERSUS McELROY/RICHARDSON STUDY

TYPE OF AIRWAY	CONDITION OF AIRWAY SURFACES	FRICTION FACTOR, K (English Units) $\times 10^{-10}$ PRESENT STUDY	FRICTION FACTOR, K (English Units) $\times 10^{-10}$ McELROY/ RICHARDSON
A) Ventilation Shafts, in Hard Rock	- concrete, gunite lined - straight sections - arched or rounded perimeter	no shaft measurements performed	62
B) Ventilated Drifts, in Hard Rock	- uncoated rock surface - irregular, rough surface - straight sections	34-65	108
C) Ventilated Drifts, in Coal	- timbered, straight sections - clean surfaces, or slightly obstructed	56-66	80-110
D) Ventilated Drifts, in Sedimentary Rock	- not timbered, straight sections - clean or slightly obstructed surfaces	58	30-75

APPENDIX 2

PHOTOPROFILE SOFTWARE LISTING

TITLE Photoprofile Areas PAGE 1 OF 1

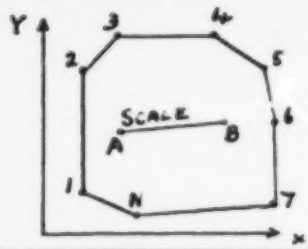
PROGRAMMER K.R. Notley DATE May 1980

TI Programmable
Program Record

Partitioning (Op 17) [4,7,9,5,9] Library Module _____ Printer Yes Cards 1

PROGRAM DESCRIPTION

This program determines the area and perimeter of an arbitrary shape traced onto graph paper



USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS	PRINTS
1.	Initialize	-	E	Profile Areas
2.	Input Branch No. or Area No.	Branch No.	A	-
3.	Input Scale Length in Field Units	Scale	R/S	-- S
4.	X-Coord of Point A	XA	R/S	--- XA
5.	Y-Coord of Point A	YA	R/S	--- YA
6.	X-Coord of Point B	XB	R/S	--- XB
7.	Y-Coord of Point B	YB	R/S	--- YB
8.	X-Coord of Point 1	X1	B	---- X
9.	Y-Coord of Point 1	Y1	R/S	---- Y
10.	X-Coord of Point 2	X2	R/S	---- X
11.	Y-Coord of Point 2	Y2	R/S	---- Y
12.	(Repeat Steps 10 & 11 for Points 3 to N)			
13.	Calculate Perimeter	--	2nd D'	--- PER
14.	Calculate Area and Print Branch or Area No.	--	D	--- AREA --- STA
15.	Start at Step 2 for next area (if an error is detected while entering coordinates, start again at step 8).			

USER DEFINED KEYS	DATA REGISTERS (INV)		LABELS (Op 08)
A	0	0	
B	1	1	
C	2	2	
D			
E			
A'			
B'			
C'	7	7	
D'	8	8	
E'	9	9	

FLAGS	0	1	2	3	4	5	6	7	8	9

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TITLE Photoprofile Areas PAGE 1 OF 1

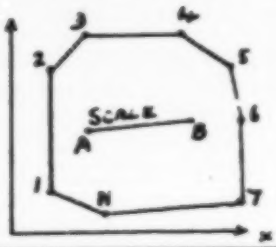
PROGRAMMER K.R. Notley DATE May 1980

TI Programmable **Program Record**

Partitioning (Op 17) [4.7.9.5.9] Library Module _____ Printer Yes Cards 1

PROGRAM DESCRIPTION

This program determines the area and perimeter of an arbitrary shape traced onto graph paper



USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			PRINTS
1.	Initialize	-	E			Profile Areas
2.	Input Branch No. or Area No.	Branch No.	A			-
3.	Input Scale Length in Field Units	Scale	R/S			-- S
4.	X-Coord of Point A	XA	R/S			--- XA
5.	Y-Coord of Point A	YA	R/S			--- YA
6.	X-Coord of Point B	XB	R/S			--- XB
7.	Y-Coord of Point B	YB	R/S			--- YB
8.	X-Coord of Point 1	X1	B			---- X
9.	Y-Coord of Point 1	Y1	R/S			---- Y
10.	X-Coord of Point 2	X2	R/S			---- X
11.	Y-Coord of Point 2	Y2	R/S			---- Y
12.	(Repeat Steps 10 & 11 for Points 3 to N)					
13.	Calculate Perimeter	--	2nd	D'		--- PER
14.	Calculate Area and Print Branch or Area No.	--	D			--- AREA --- STA
15.	Start at Step 2 for next area (if an error is detected while entering coordinates, start again at step 8).					

USER DEFINED KEYS	DATA REGISTERS (STO)		LABELS (Op 08)
A	0	0	
B	1	1	
C	2	2	
D			
E			
A'			
B'			
C'	7	7	
D'	8	8	
E'	9	9	

FLAGS	0	1	2	3	4	5	6	7	8	9

PHOTOPROFILE AREAS

000	76	LBL
001	11	A
002	47	CMS
003	42	STO
004	07	07
005	03	3
006	06	6
007	69	DP
008	04	04
009	91	R/S
010	69	DP
011	06	06
012	33	X²
013	42	STO
014	00	00
015	04	4
016	04	4
017	01	1
018	03	3
019	69	DP
020	04	04
021	91	R/S
022	69	DP
023	06	06
024	42	STO
025	01	01
026	04	4
027	05	5
028	01	1
029	03	3
030	69	DP
031	04	04
032	91	R/S
033	69	DP
034	06	06
035	42	STO
036	02	02
037	04	4
038	04	4
039	01	1
040	04	4
041	69	DP
042	04	04
043	91	R/S
044	69	DP
045	06	06
046	94	+/-
047	44	SUM
048	01	01
049	04	4
050	05	5
051	01	1
052	04	4
053	69	DP
054	04	04
055	91	R/S
056	69	DP
057	06	06
058	94	+/-
059	44	SUM
060	02	02
061	43	RCL
062	01	01
063	33	X²
064	85	+
065	43	RCL
066	02	02
067	33	X²
068	95	=
069	65	×
070	02	2
071	95	=
072	22	INV
073	49	PRD
074	00	00
075	04	4
076	04	4
077	69	DP
078	04	04
079	98	ADV
080	91	R/S
081	76	LBL
082	12	B
083	69	DP
084	06	06
085	42	STO
086	01	01
087	42	STO
088	02	02
089	00	0
090	42	STO
091	06	06
092	42	STO
093	10	10
094	04	4
095	05	5
096	69	DP
097	04	04
098	91	R/S
099	69	DP
100	06	06
101	42	STO
102	03	03
103	42	STO
104	04	04
105	04	4
106	04	4
107	69	DP
108	04	04
109	91	R/S
110	76	LBL
111	13	C
112	48	EXC
113	02	02
114	42	STO
115	09	09
116	85	+
117	43	RCL
118	02	02
119	95	=
120	42	STO
121	05	05
122	43	RCL
123	09	09
124	75	-
125	43	RCL
126	02	02
127	69	DP
128	06	06
129	95	=
130	33	X²
131	42	STO
132	09	09
133	04	4
134	05	5
135	69	DP
136	04	04
137	91	R/S
138	48	EXC
139	04	04
140	75	-
141	43	RCL
142	04	04
143	95	=
144	42	STO
145	08	08
146	65	×
147	43	RCL
148	05	05
149	95	=
150	44	SUM
151	06	06
152	43	RCL
153	08	08
154	33	X²
155	85	+

PHOTOPROFILE AREAS

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156  43  RCL
157  09   09
158  95   =
159  34  FX
160  44  SUM
161  10   10
162  43  RCL
163  04   04
164  69  DP
165  06   06
166  04   4
167  04   4
168  69  DP
169  04   04
170  91  R/S
171  13   C
172  76  LBL
173  14   D
174  98  ADV
175  01   1
176  03   3
177  03   3
178  05   5
179  01   1
180  07   7
181  04   4
182  03   3
183  69  DP
184  04   04
185  43  RCL
186  02   02
187  55   ÷
188  43  RCL
189  01   01
190  95   =
191  44  SUM
192  02   02
193  43  RCL
194  00   00
195  32  X↔T
196  06   06
197  43  RCL
198  04   04
199  69  DP
200  05   05
201  98  ADV
202  98  ADV
203  69  DP
204  00   00
205  91  R/S
206  76  LBL
207  15   E
208  06   06
209  98  ADV
210  03   3
211  06   6
212  03   3
213  07   7
214  01   1
215  03   3
216  69  DP
217  06   06
218  01   1
219  03   3
220  05   5
221  03   3
222  00   0
223  00   0
224  69  DP
225  06   06
226  43  RCL
227  03   03
228  55   ÷
229  43  RCL
230  02   02
231  95   =
232  44  SUM
233  03   03
234  43  RCL
235  00   00
236  32  X↔T
237  06   06
238  43  RCL
239  04   04
240  69  DP
241  05   05
242  98  ADV
243  98  ADV
244  69  DP
245  00   00
246  91  R/S
247  76  LBL
248  16   A'
249  43  RCL
250  02   02
251  55   ÷
252  43  RCL
253  01   01
254  95   =
255  32  X↔T
256  55   ÷
257  43  RCL
258  03   03
259  95   =
260  44  SUM
261  01   01
262  43  RCL
263  00   00
264  32  X↔T
265  06   06
266  43  RCL
267  04   04
268  69  DP
```

APPENDIX 3

INVENTORY OF EQUIPMENT UTILIZED FOR FRICTION FACTOR SURVEYS

The following summary is provided to list the necessary equipment required to conduct the friction factor survey:

ITEM	MODEL	SOURCE
MAGNEHELIC GAGE	2000, Pressure Range 0-0.50 inch w.g. (accuracy + .01 in w.g.)	Baker Instruments Limited 118 Doncaster Avenue Thornhill, Ontario L3T 1L3
MICROMANOMETER	MP6KD, Pressure Range 0-1999 Pa, Calibrated in S.I. units (accuracy of + 1 Pa)	Airflow Developments Limited 1281 Matheson Boulevard Mississauga, Ontario L4W 1R1
DIGITAL ANEMOMETER	DA-4000, Direct Reading and Integrating, Dual Scale (Imperial/Metric), (accuracy + .001 m/s)	Envirotech Services Inc. 547 Park Avenue Prairie du Sac, Wisconsin 53578
SLING PSYCHROMETERS	FT-3307, S.I. scale (accuracy + 0.5 =C)	Cole-Parmer Instrument Co. 7425 North Oak Park Avenue Chicago, Illinois 60648
TUBING	Tygon, 4.76 mm i.d. 300 meter length (2-150 m sections)	Baker Instruments Limited 118 Doncaster Avenue Thornhill, Ontario L3T 1L3
PHOTOPROFILE CAMERA	Polaroid, Model EE 100 Special	Vern Napier Camera Limited 333 Princess Street Kingston, Ontario K7L 1B7